REQUEST FOR ACTION (RFA)

1. Review Type	2. RFA No.	3. Review Date
TKUP System Requirements Review	452/230-001	April 27, 2005

4. Title

Link Margin

5. Action

Change the link margin used from 2 dB to 3 dB and make it clear that the margin is to be provided by a flight project using TKUP. This is link margin specified by Table 1.06-1 of "Rules for the design, Development, Verification, and Operations of Flight Systems" GSFC-STD-1000. Goddard Procedural Requirement (GPR) 8070.4 directs all space flight products for which GSFC is responsible to conform to the rules stated in GSFC-STD-1000 unless acceptable waivers are obtained.

Reference

Page 11, identifies a 2 dB margin

6. Originator/Organization/Telephone No./E-mail

John Martin GSFC/592/301.286.2184/John.B.Martin@nasa.gov

7. Assigned To/Organization/Telephone No./E-mail	Due Date
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/20/05

8. Response

The customer PA size as a function of data rate is attached for a 2 dB link margin (Figure 1) and a 3 dB link margin (Figure 2) when using a 1.2 meter antenna. As expected, the required PA size is higher for a 3 dB link margin.

The TKUP has a responsibility to submit recommended SNUG modifications to SN management based on the TKUP upgraded services and equipment. The 3 dB link margin specified in GSFC-STD-1000 will be included as appropriate in the proposed SNUG modifications.

During the development of the TKUP requirements, TKUP used the Modulation & Coding study to determine the maximum data rate that the TKUP receivers should support for all non-NASA and NASA customers. The potential non-NASA 2 dB link margin customer actually drives the TKUP maximum data rate requirements, not the 3 dB link margin customer. Therefore, the TKUP Requirements Specification (RS) does not require any changes even if NASA customers are restricted to 3 dB link margins. NASA customers, who must use 3 dB link margins, may want to use 600 Mbps rather than 625 Mbps in order to keep their PA size lower, but the TKUP receiver (TKUP RS) should still support 625 Mbps for non-NASA customers who may want to operate with a 2 dB link margin. Also, the point at which 8PSK starts to outperform SQPSK (410 Mbps) is not determined by the link margin parameter. Therefore, the SQPSK to 8-PSK crossover point will not change when the link margin is changed from 2 dB to 3 dB. That point is determined by the channel distortions and by how much the main lobe of the signal spectrum is filtered.

9. Response By/Organization/Telephone No./E-mail	Date Prepared
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/17/05

10. Originator Contacted	☐ No	☒ Yes	Date	5/17/05

11. Disposition	☐ Open	☐ Deferred	☒ Closed	☐ Withdrawn

12. Comments

Originator concurrence received via email on May 19, 2005.

13. Approval

Signature on file; see email dated Fri, 8 Jul 2005 08:52:41 -0600

John B. Martin

Date

Figure 1. 1.2 Meter Antenna With 2 dB Link Margin

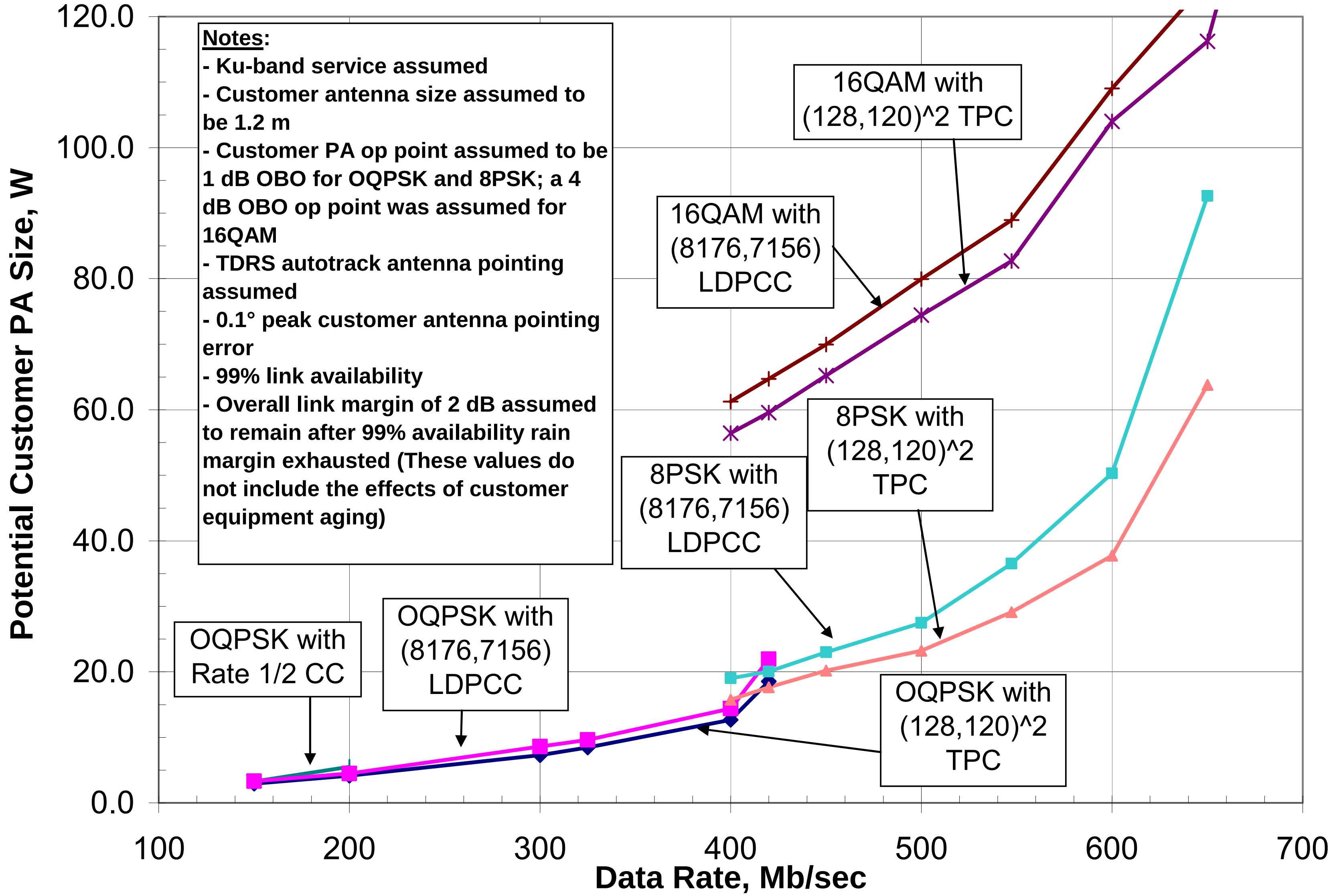
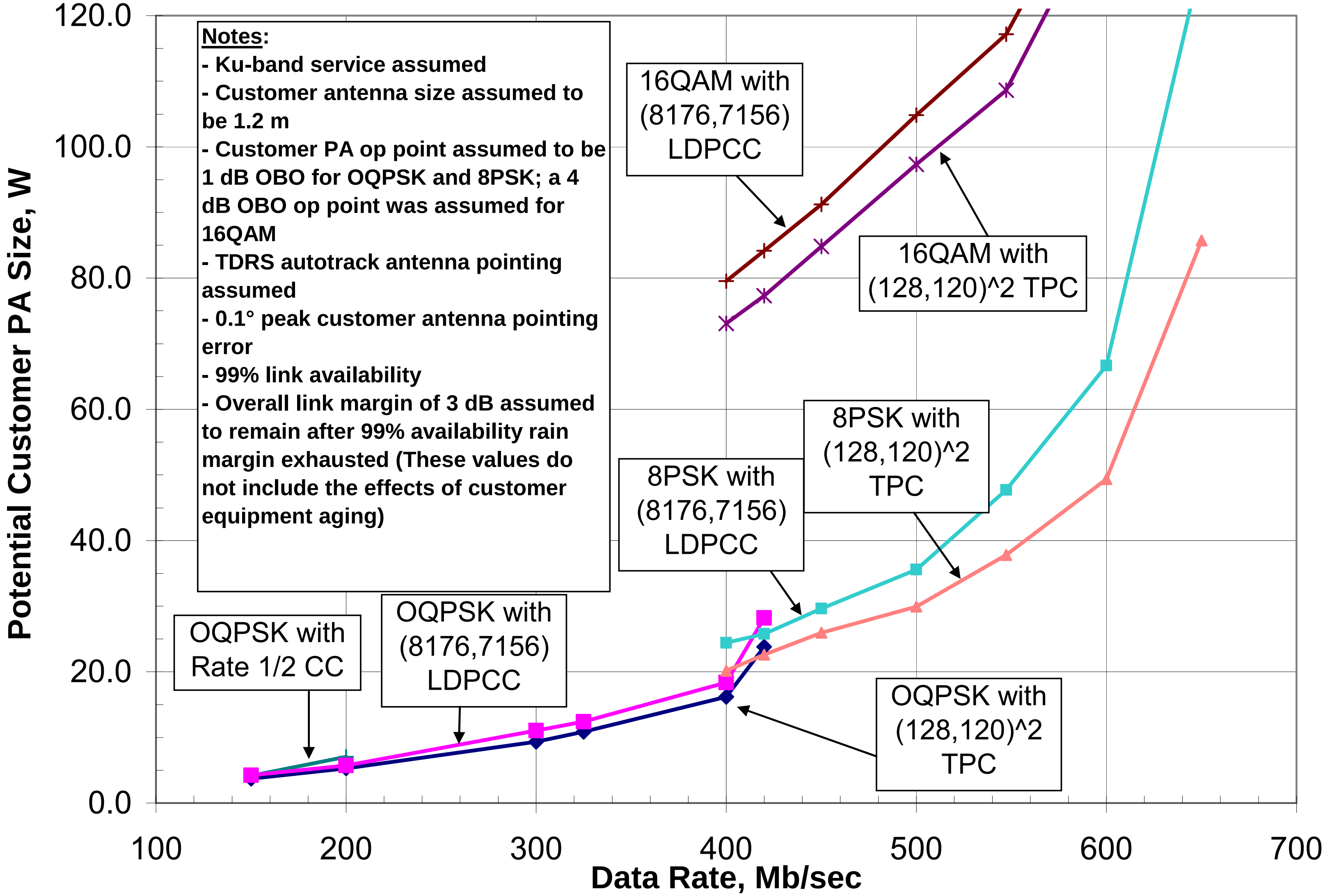


Figure 2. 1.2 Meter Antenna With 3 dB Link Margin



REQUEST FOR ACTION (RFA)		
1. Review Type TKUP System Requirements Review	2. RFA No. 452/230-002	3. Review Date April 27, 2005

4. Title

BER requirement at 10^{-9}

5. Action

Analysis performed from TKUP looks only at link format to provide BER for compressed data. However, almost all commercial standards require $<10^{-10}$ BER. TKUP looks only at burst errors in a frame assuming that the customer receives that frame in totality. However, packetization within link may require $<10^{-10}$ BER for the link as well. So that all packets/channels are $<10^{-10}$ BER.

Reference

Page 85-90

6. Originator/Organization/Telephone No./E-mail

Wai Fong/GSFC/Code 567/301.286.8165/wfong@pop700.gsfc.nasa.gov

7. Assigned To/Organization/Telephone No./E-mail	Due Date
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/13/05

8. Response

The TKUP operations concept and requirement for BER will be changed to "10^{-10} (TBR)." The TBR in the TKUP Requirement Specification indicates that the requirement will receive further analysis/evaluation as part of TKUP Demonstration.

9. Response By/Organization/Telephone No./E-mail	Date Prepared
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	6/24/05

10. Originator Contacted	☐ No	☒ Yes	Date	June 27, 2005

11. Disposition	☐ Open	☐ Deferred	☒ Closed	☐ Withdrawn

12. Comments

Originator concurrence received via email on June 27, 2005.

13. Approval

Signature on file; see email dated Fri, 8 Jul 2005 08:52:41 -0600
John B. Martin

Date

REQUEST FOR ACTION (RFA)		
1. Review Type TKUP System Requirements Review	2. RFA No. 452/230-003	3. Review Date April 27, 2005
4. Title Symbol synchronization for long code lengths		
5. Action Determine if there is a need for either longer synchronization headers or pilot words for long code lengths in order to maintain symbol synchronization, especially 8PSK modulation and what impact to receiver quality (if any) without pilot words. DVB-S2 requires pilot symbols for 64K blocks.		
Reference Page 81		
6. Originator/Organization/Telephone No./E-mail Wai Fong/GSFC/Code 567/301.286.8165/wfong@pop700.gsfc.nasa.gov		
7. Assigned To/Organization/Telephone No./E-mail John Wesdock / ITT / 703.438.8051 / John.Wesdock@itt.com		Due Date 5/13/05
8. Response This RFA response examines TKUP service carrier tracking acquisition and tracking, symbol synchronizer acquisition and tracking, and decoder acquisition and frame synchronization performance for the block codes identified in the TKUP Requirements Specification (RS) under the design constraints and the thermal noise and distortion conditions specified in the TKUP RS. In particular, this RFA response examines whether the 42 bit Frame Synchronization Marker (FSM) maximum length is appropriate for all codes identified in the TKUP RS and whether pilot symbols are required to maintain symbol synchronization. See attached write-up.		
9. Response By/Organization/Telephone No./E-mail John Wesdock / ITT / 703.438.8051 / John.Wesdock@itt.com		Date Prepared June 28, 2005
10. Originator Contacted	☐ No ☒ Yes	Date July 6, 2005
11. Disposition	☐ Open ☐ Deferred ☒ Closed ☐ Withdrawn	
12. Comments The originator concurs with the RFA response, however he contends the frame synchronization marker (FSM) length of 42-bits is not practical even though it has been shown to do the job and should be a multiple of 16-bits to facilitate computer processing and storage. The TKUP PM concurs that the FSM length should be a multiple of 8 for practical design purposes; however the intent of the TKUP FSM length requirement is to specify a maximum length and not a specific design for the implementation. This allows the vendor the flexibility to determine the FSM length used, including whether it is a multiple of 8- or 16-bits, and meet the other TKUP performance requirements. The FSM length has been identified as a very low technical risk relative to the overall TKUP design/implementation in meeting the TKUP performance requirements. That said the vendor implementation will be evaluated, and in fact, the TKUP Demonstration will provide ample insight into the design prior to a contract being awarded for the TKUP implementation phase. Therefore the FSM length requirement (4.3.7.4.b) will remain as specified in the 452-RS-TKUP.		
13. Approval	Signature on file; see email dated Wed, 14 Sep 2005 19:03:08 -0400 John B. Martin	Date

TKUP SRR RFA 003 – Symbol Synchronization and Frame Sync Marker for Long Code Lengths

1.0 Background

The pre-SRR draft of the TKUP Requirements Specification (RS) required the TKUP equipment be capable of:

1. Conducting carrier acquisition, bit acquisition on each channel, and decoder acquisition on the Customer platform signal in ≤1 second with a probability ≥0.9 when the Customer center frequency uncertainty is ≤±21 kHz. This requirement must be met under the following conditions:
   - C/No at SGLT Antenna Subsystem output ≥ 70 dB-Hz or that required to achieve Eb/No commensurate with the theoretical plus implementation loss values that are specified in Section 4.3.9 of the TKUP RS for a BER of 10^{-5}, whichever is greater.
   - The Customer frequency dynamics as defined in Section 4.3.10 of the TKUP RS.
   - The bit transition density values as specified in Section 4.3.5.1 of the TKUP RS.
2. Providing a mean time-to-cycle-slip in carrier tracking that is ≤90 minutes for a C/No at a level that is greater than or equal to a level that is 3 dB less than that required for a BER of 10^{-5} at the output of the high rate receiver equipment.
3. Providing a mean time between bit slips of ≥ 90 minutes for the I and Q channels when bit slip is caused by a cycle slip in the bit recovery loop:
   - Bit Transition Density. NRZ symbols: ≥40%.
   - C/No. The C/No is at a level that is greater than or equal to a level that produces a BER of 10^{-5} at the output of the receiver equipment.
4. Providing a mean time between bit slips of ≥ 90 minutes for the I and Q channels when bit slip is caused by a cycle slip in the bit recovery loop:
   - Bit Transition Density. NRZ symbols: ≥25% and ≤40%.
   - C/No. The C/No is at a level that is greater than or equal to a level that is 1 dB greater than the level required for a BER of 10^{-5} at the output of the high rate receiver equipment.
5. Providing BER performance compliant with the requirements of Section 4.3.9 of the TKUP RS.

2.0 Assumptions

The following assumptions are used in the analyses presented in this RFA response:

- The minimum supported data rate for 8PSK service will be reduced to 150 Mb/sec from the 400 Mb/sec currently specified in the TKUP Requirements Specification (RS). This assumption is based upon TKUP SRR RFA #8.
- Per TKUP SRR RFA #6, an additional signal acquisition specification will be added to the TKUP RS for the new signal formats only which states the following:

  Conducting carrier acquisition, bit acquisition on each channel, and decoder acquisition on the Customer platform signal in ≤3 seconds with a probability

≥0.9 when the Customer center frequency uncertainty is ≤±54 kHz. This requirement must be met under the following conditions:

  - C/No required to achieve Eb/No commensurate with the theoretical plus implementation loss values that are specified in Section 4.3.9 of the TKUP RS for a BER of 10^{-5}, whichever is greater.
  - The Customer frequency dynamics as defined in Section 4.3.10 of the TKUP RS.
  - The bit transition density values as specified in Section 4.3.5.1 of the TKUP RS.

- Per page 74 of the Lindsey and Simon text [1] (note that Lindsey and Simon were the pioneers of the original TDRSS receiver system), the squaring loss for an N=4 Costas loop with an input C/N of 3.6 dB (minimum expected for TPC or LDPC-coded OQPSK) is approximately 6 dB. Note that the 3.6 dB minimum C/N at the input to the carrier tracking loop is based upon the minimum expected C/No for OQPSK TPC or LDPC service (which is 87.1 dB-Hz per the TKUP RS) and the service channel bandwidth (which is 225 MHz approximately).
- Per page 74 of the Lindsey and Simon text [1], the data removal loss for an N=8 Costas loop with an input C/N of 6.5 dB (minimum expected for TPC or LDPC-coded 8PSK) is between 17.8 dB and 20 dB, depending upon the ARM filter type. Note that the 6.5 dB minimum C/N at the input to the carrier tracking loop is based upon the minimum expected C/No for 8PSK TPC or LDPC service (which is 90.0 dB-Hz per updates to the TKUP RS based upon RFA #8) and the channel bandwidth (which is 225 MHz approximately).

3.0 Analysis

Analysis is presented here to demonstrate that the requirements stated in Section 1.0 of this response are collectively realizable and that they are not in contradiction with one another or the other requirements in the TKUP RS.

3.1 Carrier Acquisition

The existing Loral High Data Rate Receiver (HDRR) is required to achieve carrier acquisition within one second for an OQPSK signal with a C/No as low as 70 dB-Hz. Considering that the HDRR utilizes a carrier tracking loop bandwidth of 14 kHz during acquisition, it can be stated that the HDRR is capable of achieving carrier acquisition within one second for a loop SNR of 22.5 dB based on the following equation and calculation:

Carrier Tracking Loop SNR = C/No at Input to Receiver – Carrier Recovery Loop Filter Bandwidth – QPSK Squaring Loss

Carrier Tracking Loop SNR = 70 - 10*log(14000) - 6 = 22.5 dB

Assuming this same acquisition threshold is applicable to today's technology, analysis can be performed which shows carrier acquisition will occur nominally for the new TKUP signal structures.

3.1.1 OQPSK

The minimum data rate for which TPC and LDPC coded OQPSK is supported is 150 Mb/sec. Per the TKUP RS, a minimum C/No of 87.1 dB-Hz can be expected for

TPC- or LDPC-coded OQPSK service. A minimum C/No of 87.1 dB-Hz is based on the following equation and calculation:

Minimum C/No = Theoretical TPC Eb/No at 10^{-5} BER + Implementation Loss at 10^{-5} BER + Minimum Data Rate

Minimum C/No = 3.75 + 1.6 + 10*log(150 Mbps) = 87.1 dB-Hz

If we conservatively assume a carrier tracking loop acquisition bandwidth as wide as the maximum allowable frequency uncertainty of 54 kHz (no FFT carrier search logic in the receiver), the loop SNR would be expected to be 33.8 dB based on the following equation and calculation:

Carrier Tracking Loop SNR = C/No at Input to Receiver – Carrier Tracking Loop Filter Bandwidth – QPSK Squaring Loss in para 2.0 above

Carrier Tracking Loop SNR = 87.1 - 10*log(54000) - 6 = 33.8 dB

The value of 33.8 dB is far in excess of the 22.5 dB minimum required to achieve carrier acquisition.

3.1.2 8PSK

The minimum data rate for which TPC and LDPC-coded 8PSK is supported is currently being reduced from 400 Mb/sec to 150 Mb/sec (per TKUP SRR RFA #8). Using this new 150 Mb/sec requirement and consulting the TKUP RS, it can be shown that a minimum C/No of 90.0 dB-Hz can be expected for TPC- or LDPC-coded 8PSK service. A minimum C/No of 90.0 dB-Hz is based on the following equation and calculation:

Minimum C/No = Theoretical TPC Eb/No at 10^{-5} BER + Implementation Loss at 10^{-5} BER + Minimum Data Rate

Minimum C/No = 6.75 + 1.5 + 10*log(150 Mbps) = 90.0 dB-Hz

If we conservatively assume a carrier tracking loop acquisition bandwidth as wide as the maximum allowable frequency uncertainty of 54 kHz (no FFT carrier search logic in the receiver), the loop SNR would be expected to be 24.9 dB based on the following equation and calculation:

Carrier Tracking Loop SNR = C/No at Input to Receiver – Carrier Recovery Loop Filter Bandwidth – 8PSK Squaring Loss in para 2.0 above

Carrier Tracking Loop SNR = 90.0 - 10*log(54000) – 17.8 = 24.9 dB

This value of 24.9 dB is in excess of the 22.5 dB minimum required to achieve carrier acquisition.

If the receiver designer prefers to not overly constrain the data removal loss, a more narrow carrier acquisition bandwidth can be utilized at the expense of increased carrier acquisition complexity (e.g., a rapid frequency sweep or an FFT carrier search).

3.1.3 Discussion

Carrier acquisition can be accomplished with a bandwidth as wide as the maximum allowable frequency uncertainty without the use of acquisition aids such as pilot symbols. The receiver designer additionally has the option of utilizing a carrier tracking loop bandwidth smaller than 54 kHz to further ensure margin in the carrier acquisition process. While using a smaller carrier tracking loop bandwidth means there will be additional complexity elsewhere (e.g., an FFT-based carrier acquisition search process or a frequency sweep), this complexity is not unreasonable and is already implemented in receivers, such as WSC's Integrated Receiver.

Based upon the analysis presented, it can be stated that methods exist which do not involve the use of pilot symbols which can be used to ensure carrier acquisition occurs for the TKUP signal structures at the minimum required signal-to-noise levels. It is also worthwhile to mention that the TKUP RS does not restrict any carrier acquisition approach from being used by the implementation contractor so long as the acquisition time and probability requirements are met.

3.2 Carrier Tracking

Following carrier acquisition, the TKUP receiver would likely reduce the carrier tracking loop bandwidth down to a value appropriate for the frequency dynamics expected from a Ku- or Ka-band LEO platform (as the HDRR currently does). The existing HDRR currently uses a 1200 Hz carrier tracking loop bandwidth to support Ku/Ka-225 MHz services. Assuming this bandwidth and using analysis similar to that presented in Section 3.1, the loop SNR during carrier tracking would be expected to be 50.3 dB for OQPSK and 41.4 dB for 8PSK.

Ultimately, thermal noise inside of a carrier tracking loop gets converted into phase noise (in the loop oscillator). This mapping from thermal noise to untracked phase noise can be calculated as follows [2]:

$$\sigma_{e,N}^2 = \int_0^{\infty} \frac{N_o}{C} \cdot \left|H(f)\right|^2 \, df \quad \text{rad}^2$$

Where

$\sigma_{e,N}^2$ = untracked phase error component due to thermal noise

$\frac{C}{No}$ = carrier to noise density ratio at input to loop

$H(f)$ = carrier tracking loop transfer function

Considering that our signal is data modulated, a data removal loss term needs to be added to the above equation as follows:

$$\sigma_{e,N}^2 = \int_0^{\infty} \frac{N_o}{C \cdot L_s} \cdot \left|H(f)\right|^2 \, df \quad \text{rad}^2$$

Where

L_s = data removal loss, less than 1.0

The above equation can be approximated as follows (note that C, No, and Ls can all be pulled out of the integral and you are simply left with the definition of noise bandwidth):

$$\sigma_{e,N}^2 = \frac{1}{(\text{Loop SNR})} \quad \text{rad}^2$$

Using the loop SNR values computed earlier in this section and the assumed carrier tracking loop bandwidth of 1200 Hz, the untracked phase error contribution due to thermal noise is 3.05 mrad rms for OQPSK and 8.51 mrad rms for 8PSK. Converting to degrees rms yields 0.17 deg rms for OQPSK and 0.49 deg rms for 8PSK. These are insignificant values when put in context of the expected 3.19 deg rms of untracked phase noise due to phase noise sources other than thermal noise.

For completeness, however, the total untracked phase error is computed here as 3.194 deg rms for OQPSK and 3.227 deg rms for 8PSK (note that phase noise rss adds). Using a method based upon page 204 of the Jack Holmes Coherent Spread Spectrum textbook [3] and knowing that only untracked phase noise within the loop bandwidth or just above it contributes to cycle slipping (per deliberations during the 1997 EOS AM cycle slip problem), the MTTCS can be shown to be approximately 1.9 x 10^{77} minutes for OQPSK and 4.0 x 10^{19} minutes for 8PSK. Note that the untracked phase noise within the loop bandwidth or just above it is expected to be approximately 1.312 deg rms per Phase Noise Analysis Tool (PNAT) software runs.

Based upon the analysis presented here, it can be seen that thermal noise is not expected to drive the MTTCS. Utilization of pilot symbols markers would in no way improve MTTCS, nor is there expected to be a need to improve the MTTCS values.

3.3 Symbol Synchronizer Acquisition

The discussion on symbol synchronizer acquisition must begin with a definition of the input signal. The symbol synchronizer receives its input signal from the output of the carrier tracking loop phase comparator, not the phase detector. This symbol synchronizer input signal is identical to the carrier tracking loop input signal with the following exceptions:

- It is at baseband
- It contains an untracked phase noise component directly attributable to the SNR established within the carrier tracking loop.

Note that the symbol synch input signal is not distorted by the carrier tracking loop, regardless of the type of carrier tracking loop phase detector and its associated losses, assuming a certain minimum loop SNR can be maintained in the carrier tracking loop (recall the untracked phase error due to thermal noise is insignificant for loop SNR levels below about 40 dB).

Having defined the input signal, it is necessary to define what is achievable with today's technology. The existing WSC HDRR symbol synchronizers are contractually obligated to operate as specified down to an Es/No of 3.7 dB. The existing WSC IR symbol synchronizers have been demonstrated to operate seemingly as specified down to an Es/No of nearly 0.0 dB for a distorted NRZ-style signal.

Based upon these performance metrics and knowledge that the symbol synch loop bandwidth is typically set to two times the peak jitter rate and the peak jitter rate can be no greater than 0.1% of the symbol rate, it can be stated that the existing equipment is guaranteed to work with a symbol synch loop SNR of 30.7 dB based on the following equation and calculation:

Symbol Sync Loop SNR = Es/No at Input to Receiver – 10*log(Loop Bandwidth / Symbol Rate)

Symbol Sync Loop SNR = 3.7 - 10*log(0.002) = 30.7 dB

Also, symbol synchs at WSC have been demonstrated to operate down to a loop SNR of 27.0 dB (0.0 - 10*log(0.002)). Note that these calculations disregard any SNR loss effects of the loop discriminator, however, since the analysis presented here will be largely relative, calculating an absolute discriminator loss is not necessary.

3.3.1 OQPSK

For a TPC or LDPC-coded OQPSK signal, the minimum expected symbol synch loop SNR is 31.76 dB based on the following equation and calculation:

Expected Symbol Sync Loop SNR = Expected Es/No at Input to Receiver – 10*log(Loop Bandwidth/Symbol Rate)

Where; Expected Es/No = theoretical Eb/No+10*log(7/8 code rate)+implementation loss

Therefore;

Expected Symbol Sync Loop SNR = 3.75 + 10*log(7/8)+1.6-10*log(0.002) = 31.76 dB

This SNR is greater than the minimum loop SNR for which the existing symbol synchs must contractually operate.

3.3.2 8PSK

For a TPC or LDPC-coded 8PSK signal, the minimum expected symbol synch loop SNR is 34.7 dB based on the following equation and calculation:

Expected Symbol Sync Loop SNR = Expected Es/No at Input to Receiver – 10*log(Loop Bandwidth/Symbol Rate)

Where; Expected Es/No = theoretical Eb/No+10*log(7/8 code rate)+implementation loss

Therefore;

Expected Symbol Sync Loop SNR = 6.75 + 10*log(7/8)+1.5-10*log(0.002) = 34.7 dB

Since an 8PSK symbol synchronizer discriminator (just like an OQPSK symbol synch discriminator) does not have to remove data but rather has to formulate an error signal from hard decisions and the summation of select quarter symbol integrations, the reduction in SNR through an 8PSK symbol synch discriminator would be expected to be on the order of the increase in signal amplitude levels, i.e, 10*log(4/2) dB. Even if it is assumed that there is 4 dB of additional loss through an 8PSK symbol synchronizer loop discriminator as compared to an OQPSK discriminator, the symbol synch loop SNR will still achieve the 30.7 dB threshold that the existing equipment works at.

Based upon this information, it would seem reasonable to expect a prospective TKUP 8PSK symbol synchronizer to achieve acquisition with a success rate equal to or better than that achieved by the existing WSC equipment. If, however, the implementation contractor determines that acquisition aids are required, the TKUP RS in no way restricts any symbol synch acquisition approach from being used so long as the acquisition time and probability requirements are met.

3.4 Symbol Synchronizer Tracking

The existing WSC HDRR symbol synchronizer is contractually required to meet the same 90 minute Mean-Time-To-Bit-Slip requirement as the TKUP equipment must meet. If it is assumed that the existing equipment currently meets the MTTBS requirement, the loop SNR values computed in the previous section for the TKUP signal structures would seem to indicate that the TKUP equipment can meet the 90 minute specification.

If the implementation contractor determines that this MTTBS requirement cannot be met, there are methods to improve symbol synch performance which are not in any way restricted by TKUP RS requirements. For example the symbol synch bandwidth can be reduced to 0.1%, the order of the symbol synch loop can be increased, the resolution of RFA #8 can be reconsidered, novel loop discriminators can be utilized or perhaps even the customer bit jitter rate requirement can be tightened.

3.5 Decoder Acquisition and Ongoing Frame Synchronization

To determine whether a Frame Synch Marker (FSM) length of 42 bits is sufficient to ensure reliable decoder acquisition, several basic analytical calculations can be performed, however, to truly validate this requirement, simulation methods must be pursued. See Section 4.5 for simulation results which demonstrate that the 42 bit FSM length is more than sufficient to ensure reliable decoder acquisition within just a few codeframes.

While simulation methods will be used to validate the 42 bit FSM requirement, some basic analytical relations can be stated. They are as follows:

- The required FSM length is not a strong function of codeblock length if many codeblocks are available for correlation accumulation during the decoder acquisition process. At the TKUP TPC and LDPC data rates and for the 1 second acquisition time, thousands of codeframes will be available for the decoder acquisition process. It was decided to trade the decoder acquisition time for a shorter FSM marker.
- The probability that a 42 bit FSM pattern will randomly occur in the data stream is $1/(2^{42})$. This means that every $(2^{42})*42$ bits, the FSM pattern is likely to randomly occur in the data stream. For a 625 Mb/sec data rate, this means the FSM is likely to occur randomly every 3.4 days, assuming continuous ongoing communications.

4.0 Simulation

In addition to the analytical work presented here, applicable simulation results have been generated as part of the KaDS Modulation and Coding Study, the TKUP Modulation and Coding Study, and as disposition of this RFA.

4.1 Carrier Acquisition

Because it could be shown via analysis that the C/No values expected for TKUP services were well in excess of the minimum C/No required for acquisition with the existing equipment, carrier acquisition was not simulated during the TKUP Modulation and Coding study. The analysis supports that carrier acquisition is feasible without acquisition aids, such as pilot symbols.

4.2 Carrier Tracking

Simulations were performed during the TKUP and KaDS modulation and coding studies to evaluate the carrier tracking performance of OQPSK, 8PSK, and 16PSK in the presence of the thermal noise and input phase noise. While these simulations were at C/No levels more commensurate with the TKUP data rates prior to RFA #8, they indicated no carrier tracking problems whatsoever. The analysis indicates that carrier tracking should be as good or better than that currently achieved at WSC.

4.3 Symbol Synchronizer Acquisition

Because it could be shown via analysis that the symbol synch loop SNR values were expected to be higher than those currently required for acquisition with the existing equipment, symbol synch acquisition was not simulated during the TKUP Modulation and Coding study. The analysis supports that symbol synch acquisition is likely feasible without acquisition aids, such as pilot symbols.

It must also be noted that the time constraints of the KaDS and TKUP modulation and coding studies did not allow for the months-worth of development time required to build data–derived symbol synchronizers for all of the modulation schemes considered.

4.4 Symbol Synchronizer Tracking

Because it could be shown via analysis that the symbol synch loop SNR values were expected to be higher than those currently required for nominal tracking with the existing equipment, data-derived symbol synchronizer timing was not simulated during the TKUP Modulation and Coding study. The analysis indicates that symbol synch tracking should be as good or better than that currently achieved at WSC. Also note that data bit jitter cannot be accurately simulated and is, therefore, evaluated analytically.

4.5 Decoder Acquisition and Ongoing Frame Synchronization

Monte Carlo simulations were performed as part of this RFA resolution to demonstrate that a 42 bit FSM length is more than long enough to ensure decoder acquisition. The following decoder acquisition simulation model was implemented in Excel:

- 42 bit FSM length
- Very undesirable FSM chosen:
  110011100011110000111110000011001110001111
- 65536 + 42 codeframe length
- Es/No = 3.65 dB (this is lower than what is the minimum required Es/No per the TKUP RS)
- Decoder continuously performs 42 bit length correlation between local FSM and incoming symbols
- 65578 correlation accumulations are maintained for each possible alignment states. This can be expressed algebraically as follows:

  $$\mathrm{Y}[m] = \frac{1}{10}\sum_{k=1}^{10}\sum_{n=1}^{42}\frac{1}{42}\cdot F[n]\cdot D[m+n-1,k]$$

  Where

  Y = Accumulated correlation value
  F = Frame Sync Marker
  D = Noise corrupted received data
  k = Codeframe evaluation index
  n = Frame Sync Marker index
  m = Data index

- When the peak accumulated correlation value is 30 dB greater than the average accumulated correlation value, acquisition is declared. For all simulations, this occurred within 10 codeframes.
- Floating point mathematics considered as well as 1 bit mathematics.
- Symbol timing is provided to the decoder by the symbol synchronizer.

Fifty acquisition trials were performed for both quantization scenarios. For all trials, decoder frame synchronization was achieved per the algorithm described above, i.e, the noise-corrupted FSM was identified among the noise-corrupted symbols. The following two tables provide the simulation results for the two quantization scenarios:

Decoder Acquisition Simulation Results Assuming Floating Point Multiplications

Trial #	Statistical Metrics			
	Peak Accumulated Correlation Value	**Does Peak Occur at FSM?**	**Average Accumulated Correlation Value(1)**	**Peak to Average**
1	0.961045	Yes	0.000379	34.04105
2	0.99503	Yes	0.000447	33.47529
3	1.014941	Yes	0.000353	34.58666
4	0.96258	Yes	0.000568	32.29088
5	0.993775	Yes	0.000407	33.87694
6	1.002447	Yes	0.000281	35.52355
7	0.97004	Yes	0.000353	34.39015
8	1.009317	Yes	0.000365	34.41735
9	1.032553	Yes	0.000327	34.99365
10	0.981929	Yes	0.000382	34.10017
11	1.028324	Yes	0.000463	33.46454
12	0.995051	Yes	0.000385	34.12452
13	1.038396	Yes	0.000362	34.57261
14	1.003447	Yes	0.000176	37.55519
15	0.992765	Yes	0.000421	33.72969
16	0.977083	Yes	0.000299	35.14657
17	1.01098	Yes	0.000401	34.01854
18	1.007161	Yes	0.000387	34.15423
19	0.98711	Yes	0.000419	33.72243
20	0.979357	Yes	0.000432	33.55182
21	1.042066	Yes	0.000322	35.09597
22	1.00461	Yes	0.000506	32.97463
23	1.019293	Yes	0.000477	33.30176
24	1.017576	Yes	0.000454	33.50304
25	1.021806	Yes	0.000416	33.90048
26	1.012848	Yes	0.000427	33.74616
27	1.007741	Yes	0.000333	34.80279
28	1.031899	Yes	0.000322	35.05124
29	1.022677	Yes	0.000544	32.73945
30	1.006319	Yes	0.000389	34.12898
31	0.981852	Yes	0.00047	33.19651
32	1.001628	Yes	0.000268	35.73174
33	0.958662	Yes	0.000376	34.07038
34	0.994507	Yes	0.000204	36.8725
35	1.033901	Yes	0.000345	34.77059
36	1.013821	Yes	0.000292	35.40351
37	0.980015	Yes	0.00039	34.00124
38	0.999627	Yes	0.000355	34.50098
39	1.027224	Yes	0.000436	33.72504
40	0.987248	Yes	0.000477	33.1622
41	0.976322	Yes	0.00029	35.27476
42	0.981881	Yes	0.000515	32.80235
43	1.03812	Yes	0.000547	32.7789
44	0.981929	Yes	0.000382	34.10371
45	1.020828	Yes	0.000466	33.40458
46	0.994927	Yes	0.000546	32.60472
47	0.9854	Yes	0.000322	34.85226

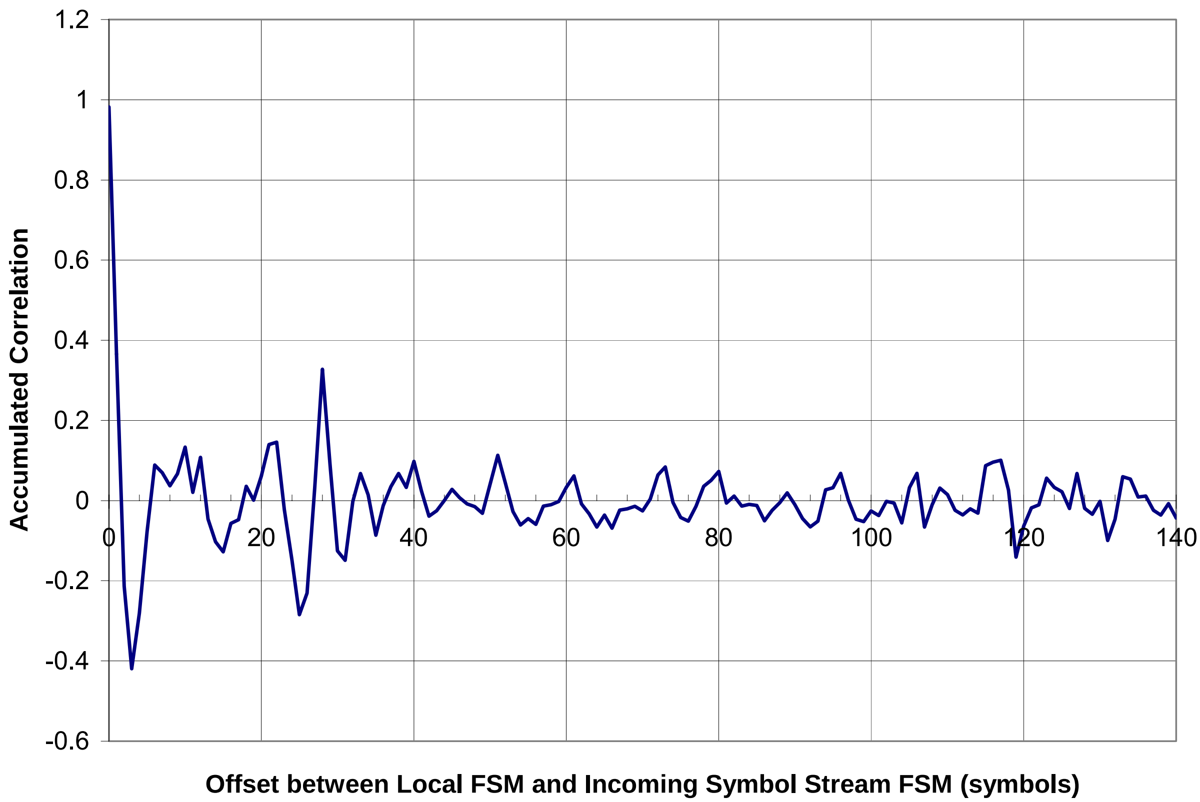
48	1.019056	Yes	0.000385	34.23245
49	1.014033	Yes	0.00051	32.98206
50	0.957853	Yes	0.000285	35.27215
Notes: 1. Peak value excluded from average calculation.				

Decoder Acquisition Simulation Results Assuming 1 Bit Multiplications

Trial #	Statistical Metrics			
	Peak Accumulated Correlation Value	Does Peak Occur at FSM?	Average Accumulated Correlation Value(1)	Peak to Average
1	0.9619048	Yes	0.0004566	33.23635
2	0.9761905	Yes	0.0004907	32.98746
3	0.947619	Yes	0.0004055	33.68617
4	0.9761905	Yes	0.0004659	33.21237
5	0.9666667	Yes	0.0004118	33.7058
6	0.9619048	Yes	0.0004196	33.60277
7	0.9666667	Yes	0.0003257	34.7244
8	0.9714286	Yes	0.0003815	34.05889
9	0.9666667	Yes	0.000351	34.39911
10	0.9714286	Yes	0.0004501	33.34106
11	0.9714286	Yes	0.000425	33.59071
12	0.9857143	Yes	0.0004716	33.2016
13	0.9809524	Yes	0.0004478	33.40555
14	0.9714286	Yes	0.0003543	34.38057
15	0.9619048	Yes	0.0003783	34.05312
16	0.9714286	Yes	0.0003371	34.59597
17	0.9571429	Yes	0.0003726	34.09767
18	0.9619048	Yes	0.0003897	33.92386
19	0.9666667	Yes	0.000485	32.99578
20	0.9666667	Yes	0.0004678	33.15208
21	0.9809524	Yes	0.0004301	33.58083
22	0.9761905	Yes	0.000439	33.47023
23	0.952381	Yes	0.000451	33.24588
24	0.9571429	Yes	0.0004286	33.48954
25	0.9809524	Yes	0.0004101	33.78763
26	0.9619048	Yes	0.0004341	33.45547
27	0.9571429	Yes	0.0004242	33.53416
28	0.9809524	Yes	0.0005257	32.70898
29	0.9857143	Yes	0.0004512	33.39345
30	0.9666667	Yes	0.0004716	33.11685
31	0.9761905	Yes	0.0004088	33.78064
32	0.9809524	Yes	0.0003474	34.50782
33	0.9761905	Yes	0.0005029	32.8809
34	0.9571429	Yes	0.0003724	34.09989
35	0.9666667	Yes	0.0003554	34.34524
36	0.9761905	Yes	0.0003861	34.0284
37	0.947619	Yes	0.0004385	33.34688
38	0.9761905	Yes	0.0003966	33.91213
39	0.9666667	Yes	0.0005337	32.57968
40	0.9571429	Yes	0.0003922	33.8748
41	0.947619	Yes	0.000433	33.40194
42	0.9666667	Yes	0.0004575	33.24863
43	0.9857143	Yes	0.0003943	33.9794
44	0.9714286	Yes	0.0004057	33.79191

45	0.9761905	Yes	0.0004442	33.41965
46	0.9666667	Yes	0.0004213	33.60651
47	0.971429	Yes	0.000442	33.41895
48	0.971429	Yes	0.000481	33.05137
49	0.980952	Yes	0.000442	33.46132
50	0.961905	Yes	0.000431	33.48415
Notes: 1. Peak value excluded from average calculation.				

The following plot provides insight into the statistics of the accumulated correlations for a selection of the 65578 alignment states:



Based upon the results of these acquisition simulations, it should be clear that decoder acquisition is certainly feasible with a 42 bit length FSM, even if the larger block TPC code is utilized.

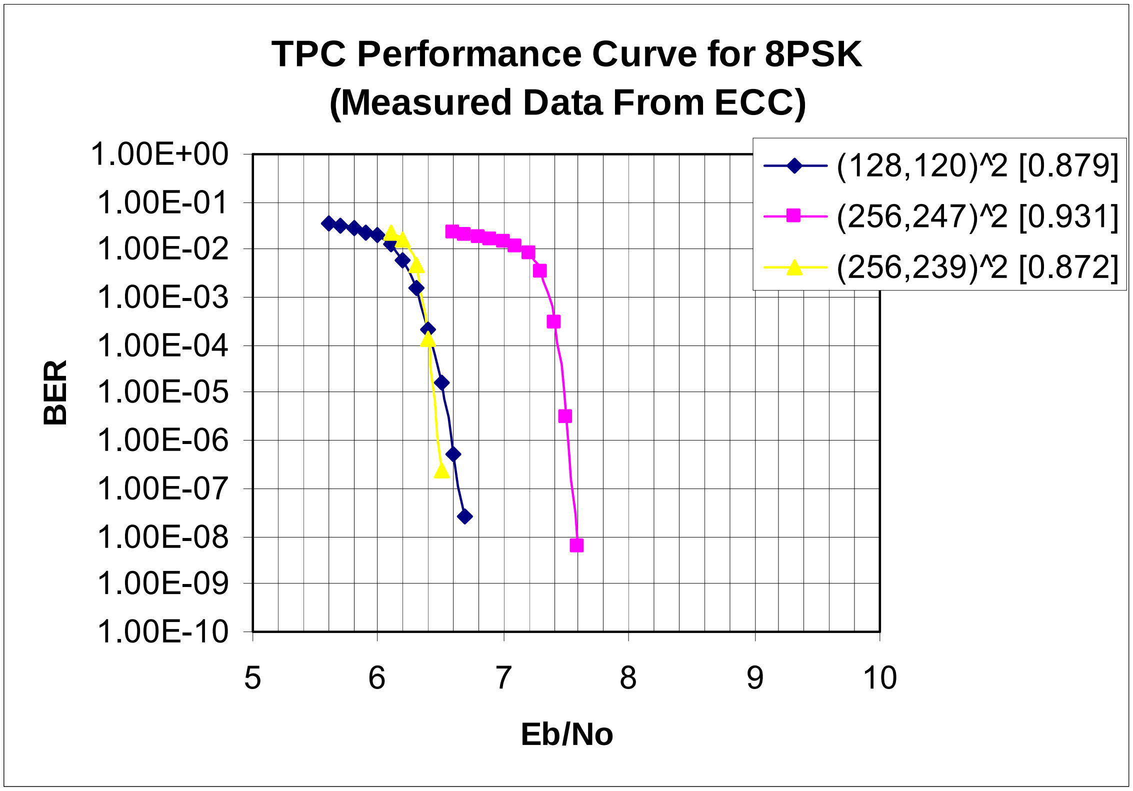
5.0 Existing Systems and Applicable Demonstrations

5.1 Symbol Synchronizer & Pilot Symbols

The characteristics of known existing 8-PSK/TPC systems and their performance during demonstrations at the TKUP data rates also supports the conclusion that pilot symbols are not required for TKUP symbol synchronization or tracking. That supporting information is as follows:

a. ECC Vendor Demonstration & Tests: Higher order modulation with low Es/No values and without pilot symbols was demonstrated at the ECC facilities to GSFC personnel. No issues with symbol synchronization were observed. Also, after the TKUP SRR, ECC stated that their (128,120)^2 code is used in the iPSTAR system for Shin Satellite Company at modulations of QPSK, 8-ary, and 16-ary. ECC stated that currently, there are approximately 10,000 terminals operating over standard Ku band satellites with the (128,120)^2 code. ECC has also run (256,239)^2 16-ary tests over a RF link between two remote terminals.

b. Vendor Meetings: At meetings with several possible receiver vendors, 8-PSK with a rate 7/8 TPC code was discussed. The vendors indicated that no potential problems are expected with a rate 7/8 TPC. Also, ECC provided 8-PSK measurement data at low Eb/No values with a rate 7/8 TPC. The ECC measured data is as follows:



However, the TKUP demo RFP will not preclude pilot symbols if a vendor wants to propose that technique in order to meet the TKUP requirements. Also, the demo RFP can ask the vendor to state whether their receiver will use data aided acquisition, pilot symbols, or neither. After the TKUP demonstration in CY2006, the need for a pilot symbol requirement can be re-addressed.

5.2 Frame Sync Marker Length For 64K Blocks

Based on actual test results provided by ECC about their existing 64K block decoders, a frame sync marker length of 32 bits works well without problems.

6.0 Conclusions

Based on the above simulation results, above analyses, vendor demonstration results, vendor meetings, and the TKUP Modulation & Coding Study, TKUP believes that the

TKUP demonstration with actual hardware, rather than additional simulations and analyses, should be the next step for the TKUP in order to verify the viability of the proposed new TKUP receiver.

7.0 References

[1] *Telecommunication Systems Engineering*, William Lindsey, Marvin Simon, Dover Publications, © 1973.

[2] *Phase Coherency in Tracking and Data Relay Satellites*, Robert Gagliardi, IEEE Transactions on Communications, Vol. Com-27, No. 10, October 1979.

[3] *Coherent Spread Spectrum Systems*, Jack K. Holmes, Wiley-Interscience, © 1982.

REQUEST FOR ACTION (RFA)		
1. *Review Type* TKUP System Requirements Review	2. *RFA No.* 452/230-004	3. *Review Date* April 27, 2005

4. *Title*	Ku ephemeris uncertainty
5. *Action*	Provide ephemeris uncertainty requirement for Ku services outside the Primary Elliptical Field of View. Refer to TDRS Specification SY-011.
Reference	Page 96
6. *Originator/Organization/Telephone No./E-mail*	Al Berndt/GSFC/Code 454/301.286.1451/aberndt@pop400.gsfc.nasa.gov

7. *Assigned To/Organization/Telephone No./E-mail*	*Due Date*
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/13/05

8. *Response*

The ephemeris uncertainty of ≤±3.2 seconds for the TDRS F8-F10 Ku extended elliptical FOV (EEFOV) will be added to the TKUP Requirements Specification, paragraph 4.4.2.

The traceability for the recommended requirement is 450-SNUG, Table 7-7.

9. *Response By/Organization/Telephone No./E-mail*	*Date Prepared*
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/09/05

10. *Originator Contacted*	☐ No	☒ Yes	*Date*	5/10/05

11. *Disposition*	☐ Open	☐ Deferred	☒ Closed	☐ Withdrawn

12. *Comments*

Originator concurrence received via email on May 11, 2005.

13. *Approval*

Signature on file; see email dated Fri, 8 Jul 2005 08:52:41 -0600

John B. Martin

Date

450-FORM-0002 (05/04)
Revision 2

REQUEST FOR ACTION (RFA)		
1. *Review Type* TKUP System Requirements Review	2. *RFA No.* 452/230-005	3. *Review Date* April 27, 2005

4. *Title*
Question about modulation and coding for commercial data rates from smaller antennas

5. *Action*
Run the simulations to determine modulation and coding recommendations for OC-3 (155 Mbps), dual OC-3 (310 Mbps), and OC-12 (622 Mbps) from smaller antennas. (i.e., What modulation and coding would be best for the customers at those data rates?)

Reference
Page 11, TKUP Modulation and Coding Study

6. *Originator/Organization/Telephone No./E-mail*
Jon Cummings/SRA/703.697.0810/Jon_Cummings@comcast.net

7. *Assigned To/Organization/Telephone No./E-mail*	*Due Date*
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/20/05

8. *Response*
Please see the attached response for the requested analysis & results.

9. *Response By/Organization/Telephone No./E-mail*	*Date Prepared*
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/19/05

10. *Originator Contacted*	☐ *No*	☒ *Yes*	*Date*	5/19/05

11. *Disposition*	☐ *Open*	☐ *Deferred*	☒ *Closed*	☐ *Withdrawn*

12. *Comments*
Originator concurrence received via email on May 19, 2005.

13. *Approval*

Signature on file; see email dated Fri, 8 Jul 2005 08:52:41 -0600
John B. Martin

Date

1.0 General Analysis and Results For Smaller Antennas

The customer PA size as a function of data rate for antenna sizes from 0.4 m to 1.2 m is attached. The attachment also includes results for both a 2 dB link margin and a 3 dB link margin. As expected, the required PA size for a 0.4 m antenna is a lot higher than the PA size required for a 1.2 meter antenna. For the higher TKUP data rates, the required PA size is not practical for a 0.4 m antenna at data rates over 350 Mbps.

2.0 Specific Response to RFA "Action"

2.1 0.4 Meter Antenna Analysis and Results

Based on the attached plots (Figures 1 and 2) for a 0.4 m antenna, only the 155 Mbps and 310 Mbps commercial data rates can be supported with practical PA sizes when using OQPSK (SQPSK) and TPC or LDPC coding. Using 8-PSK with a 0.4 meter antenna to achieve higher data rates is not practical.

2.2 0.8 Meter Antenna Analysis and Results

Based on the attached plots (Figures 3 and 4) for a 0.8 m antenna, only the 155 Mbps and 310 Mbps commercial rates can be supported with practical PA sizes (PA sizes < 100 Watts) when using OQPSK and TPC or LDPC coding.

622 Mbps can not be supported with a 0.8 m antenna and PA sizes below 100 Watts. However, based on the attached plot, Figure 3, data rates up to about 622 Mbps can be supported with a 0.8 m antenna and a 120 Watt PA if the customer uses 8-PSK, TPC coding, and a 2 dB link margin.

3.0 Scope of TKUP Modulation & Coding Study

During the development of the TKUP requirements, TKUP used the Modulation & Coding study to determine the maximum data rate that the TKUP receivers should support for all customers, including customers that use a small antenna (0.4 meter) and customers that use a relatively medium-size antenna (1.2 meter). The 1.2 meter antenna customer actually drives the TKUP maximum data rate requirements, not the smaller antenna customer. Therefore, the TKUP Requirements Specification (RS) does not require any changes. Customers, who must use a 0.4 meter antenna, can use lower data rates in order to keep their PA size at practical levels, but the TKUP receiver (TKUP RS) should still support 625 Mbps for customers who may want to operate with a 1.2 meter antenna. Also, the point at which 8PSK starts to outperform SQPSK (410 Mbps) is not determined by the antenna size. That point is determined by the channel distortions and by how much the main lobe of the signal spectrum is filtered.

Figure 1. 0.4 Meter Antenna With 2 dB Link Margin

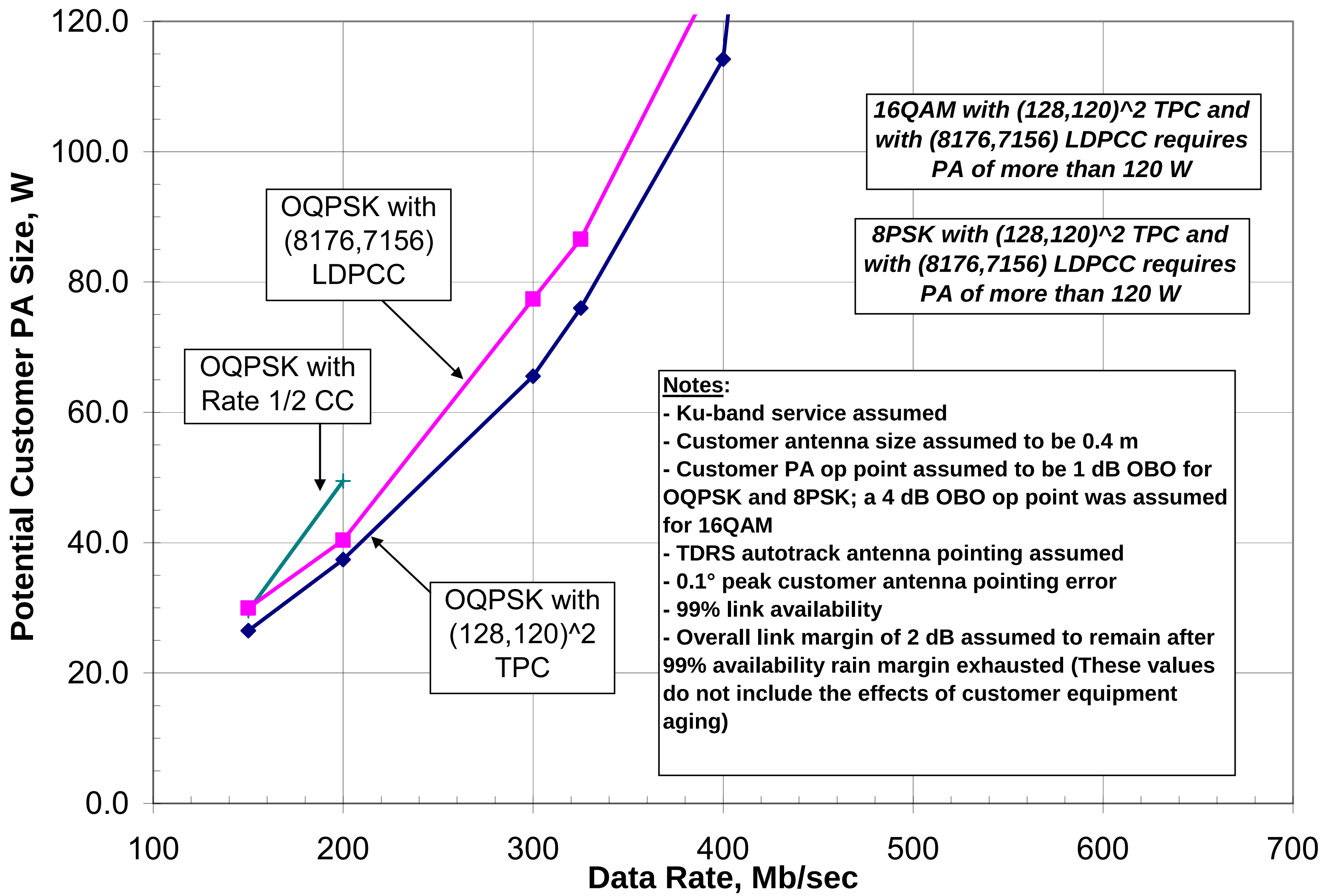


Figure 2. 0.4 Meter Antenna With 3 dB Link Margin

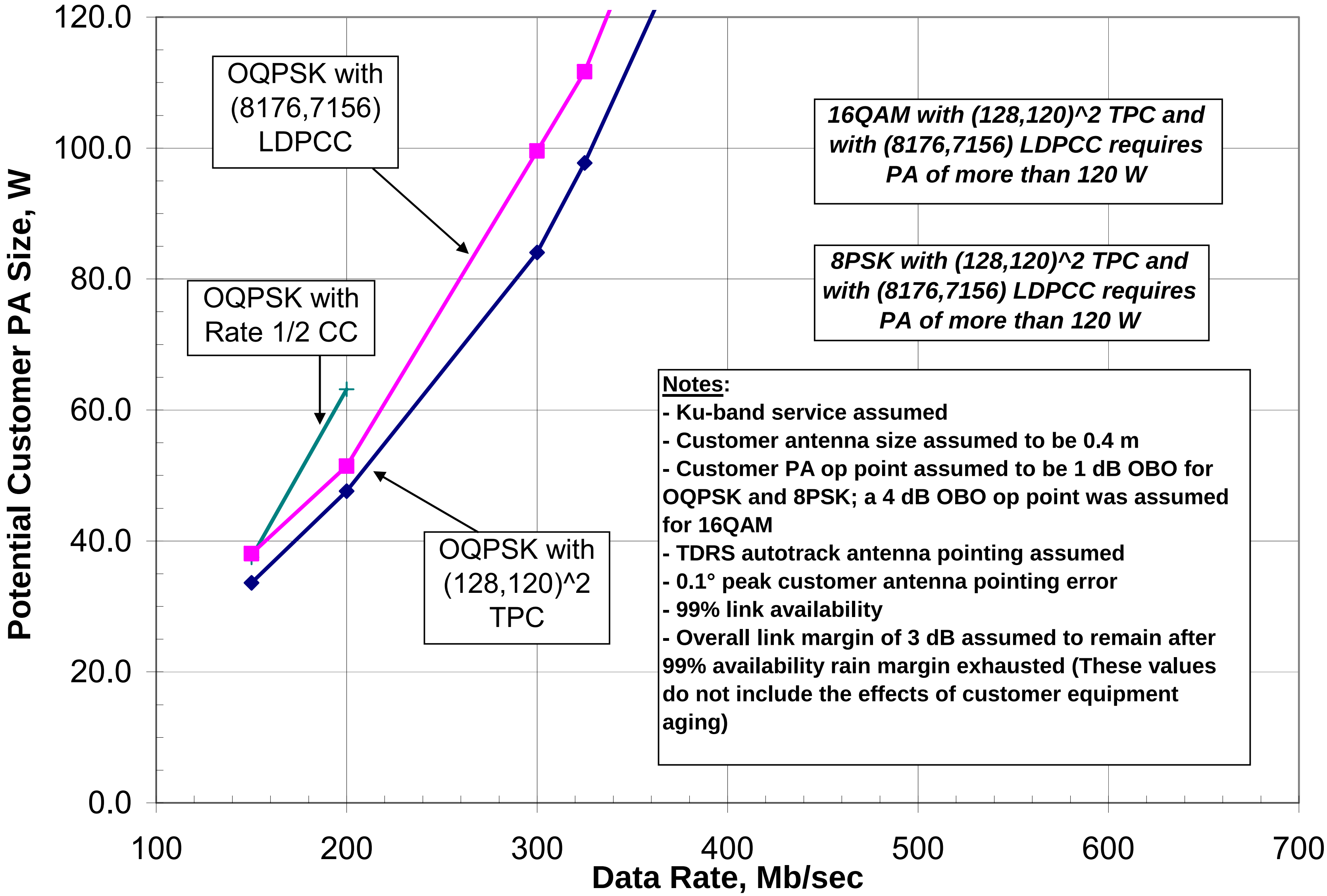


Figure 3. 0.8 Meter Antenna With 2 dB Link Margin

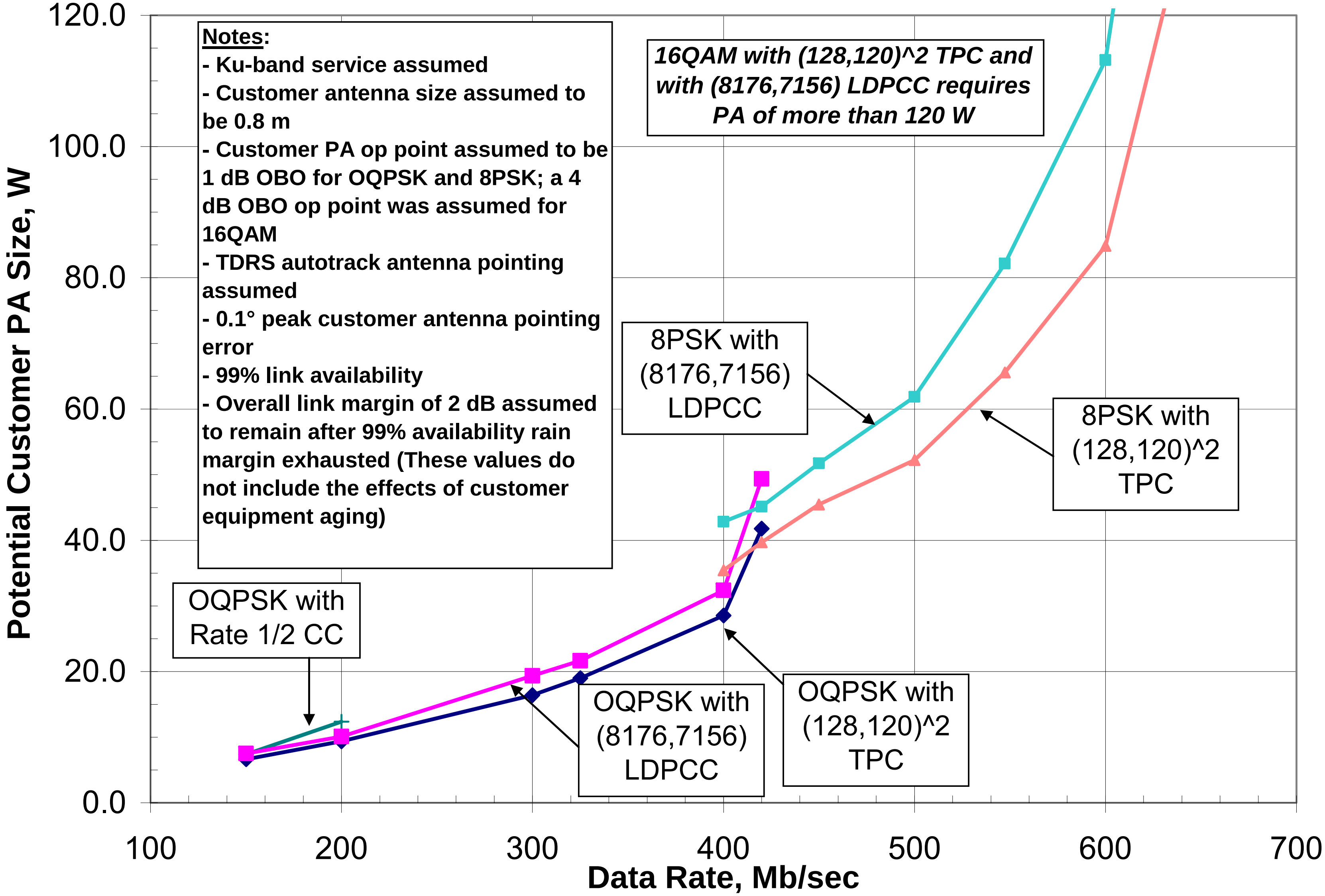


Figure 4. 0.8 Meter Antenna With 3 dB Link Margin

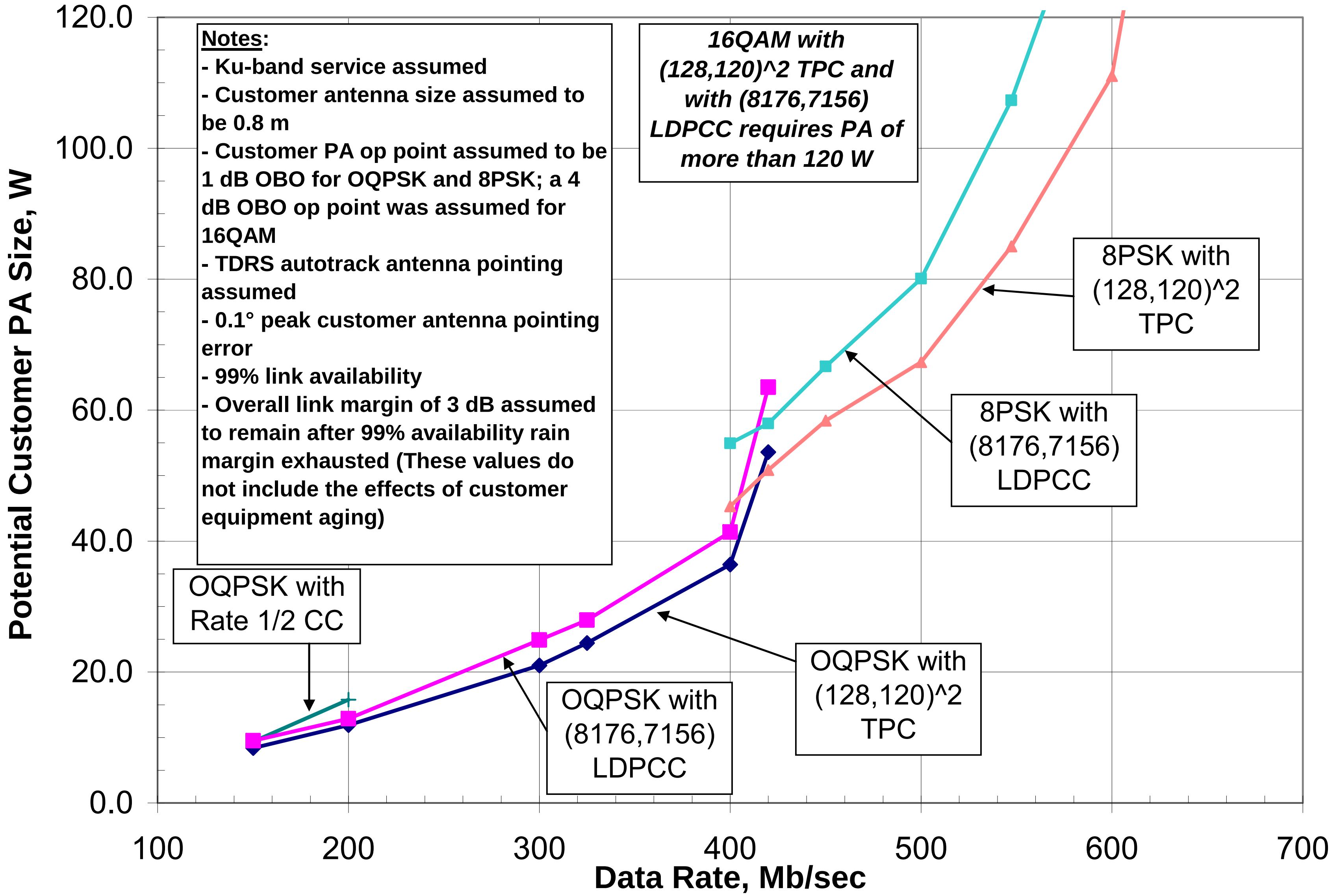


Figure 5. 1.2 Meter Antenna With 2 dB Link Margin

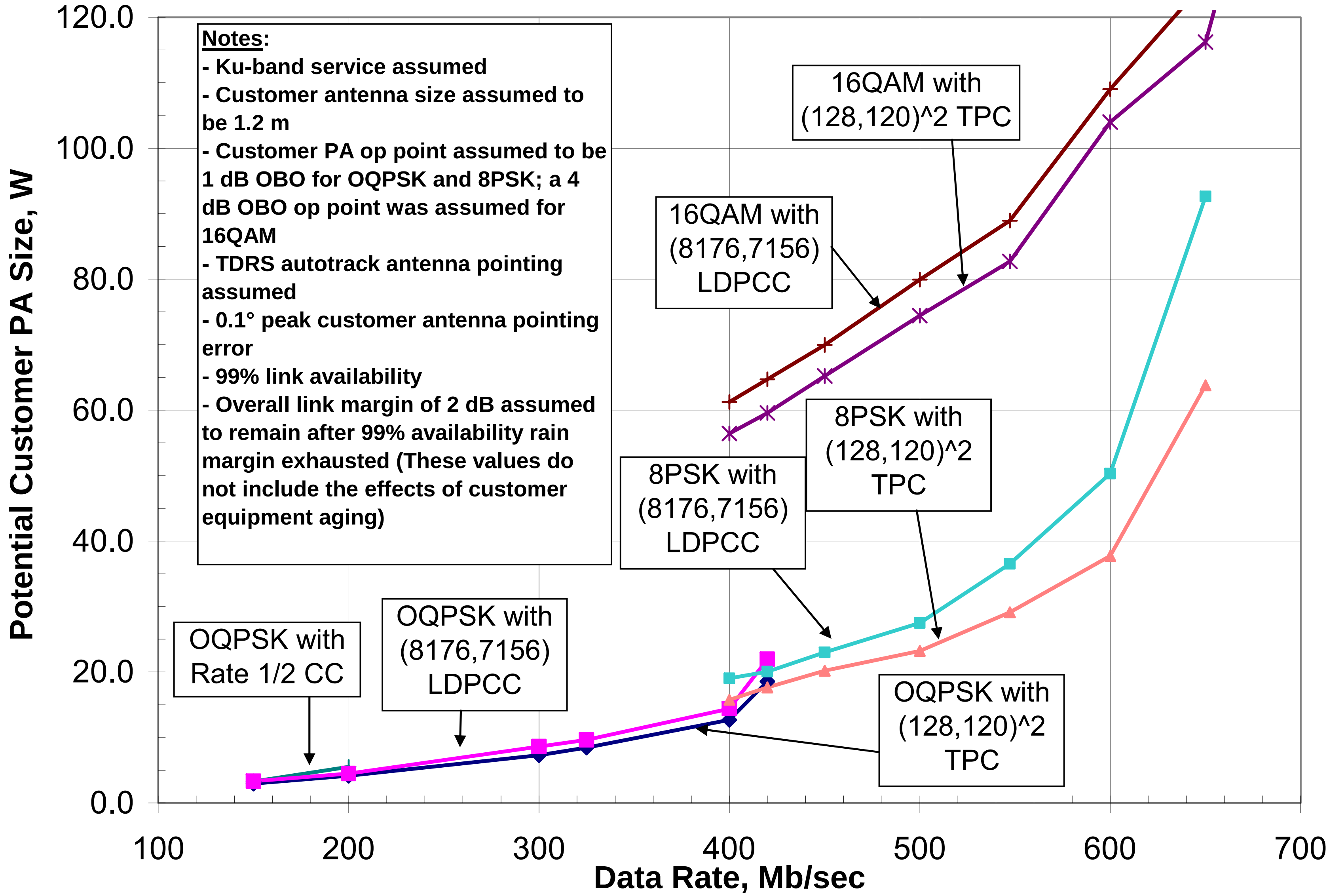
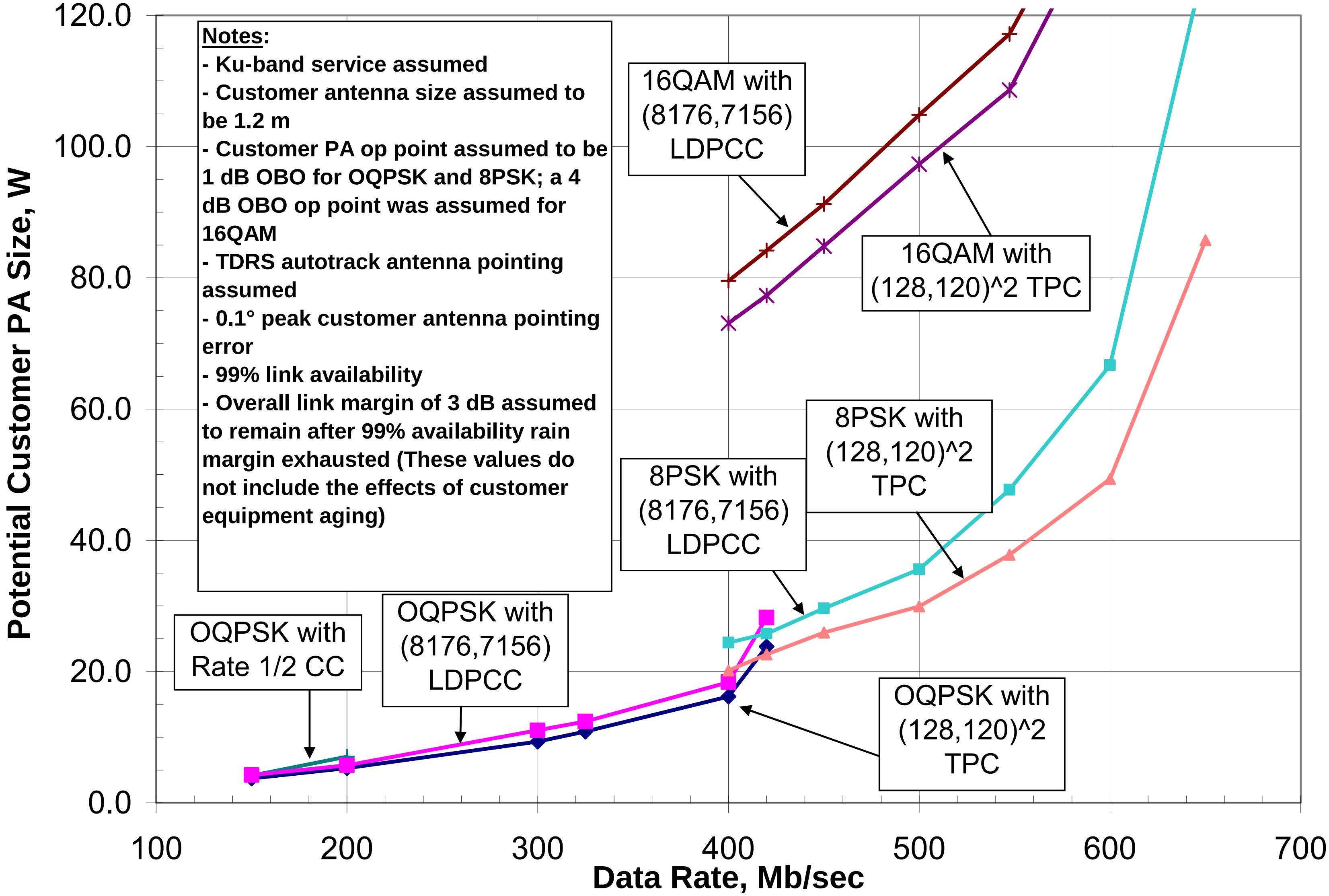


Figure 6. 1.2 Meter Antenna With 3 dB Link Margin



REQUEST FOR ACTION (RFA)		
1. *Review Type* TKUP System Requirements Review	2. *RFA No.* 452/230-006	3. *Review Date* April 27, 2005

4. *Title*
Center frequency uncertainty

5. *Action*
Consider loosening the <u><+</u>21 KHZ requirement.

Reference
Page 71

6. *Originator/Organization/Telephone No./E-mail*
Ken Perko/GSFC/Code 567/ for Victor Sank/MEI/Code 567/301.286.2645/
Victor.Sank@gsfc.nasa.gov

7. *Assigned To/Organization/Telephone No./E-mail*	*Due Date*
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/13/05

8. *Response*
Incorporate comment by changing current TKUP requirement as follows:

From: ≤±21 kHz with 1 second acquisition for all legacy and new signal formats

To: ≤±21 kHz with 1 second acquisition for all legacy and new signal formats
≤±54 kHz with 3 second acquisition for new signal formats only

Please see attachment for requirement traceability and justification for new requirement.

9. *Response By/Organization/Telephone No./E-mail*	*Date Prepared*
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/13/05

10. *Originator Contacted*	☐ *No*	☒ *Yes*	*Date*	5/16/05

11. *Disposition*	☐ *Open*	☐ *Deferred*	☒ *Closed*	☐ *Withdrawn*

12. *Comments*
Originator concurrence received via email on May 16, 2005.

13. *Approval*

Signature on file; see email dated Fri, 8 Jul 2005 08:52:41 -0600
John B. Martin

Date

1.0 Requirement Traceability

Based on meetings with receiver vendors in 2003 and 2004 during the Ka-Band Data Services (KaDS) project, the current ≤±21 kHz requirement in the SNUG (450-SNUG, revision 8, Table 8-7) can be widened for the new receivers and was widened in the TKUP Requirements Specification (RS) as follows:

Current SNUG requirement:	≤±06 kHz with 1 second acquisition ≤±21 kHz with <u>3 second acquisition</u>
Current TKUP RS requirement:	≤±21 kHz with <u>1 second acquisition</u>

Also, the attached memo provides the traceability for the ≤±21 kHz requirement that was derived when the Ka-band services were added to the SN. Specifically, the ≤±21 kHz requirement was based on the current WSC receiver acquisition search range capability and known capabilities of space qualified oven controlled crystal oscillators (OCXO). Therefore, it can be argued that the ≤±21 kHz requirement is not really a WSC legacy requirement that must be maintained.

The change from a 3 second acquisition time to a 1 second acquisition time for ≤±21 kHz was not considered a significant SNUG change based on conversations with potential receiver vendors during the KaDS Project.

Also, "Customer center frequency uncertainty" will be changed to "Customer oscillator uncertainty" in paragraphs 4.3.3.1 and 4.3.3.2 of the TKUP RS. The total Customer center frequency uncertainty that the receiver must support is the sum of the "customer oscillator uncertainty" and the "Doppler uncertainty" resulting from the ephemeris uncertainty as stated in part B of the attached memo.

2.0 Justification for new requirement

2.1 Justification for ≤±54 kHz requirement for New Signal Formats

Based on vendor product specifications, more inexpensive space qualified OCXOs could be considered by customers if the ≤±21 kHz requirement for customers is relaxed. Also, customers could consider simpler Temperature Compensated Crystal Oscillators (TCXO) if the ≤±21 kHz requirement is relaxed.

Based on product specifications, a space qualified TCXO from Vectron has the following characteristics:

a. <u>Temperature Stability</u>: $\pm 1x10^{-6}$ accuracy over -20ºC to +70ºC

b. <u>Aging</u>: $\pm 1x10^{-6}$ per year

Therefore, the total frequency uncertainty at a given moment would be $\pm 2x10^{-6}$ assuming the customer will measure the exact center frequency once/year during the mission. At 27.0 GHz, $\pm 2x10^{-6}$ yields the ≤±54 kHz requirement. Based on meetings with receiver vendors during the KaDS project, a customer oscillator uncertainty of ±54 kHz can be supported.

The 3 second acquisition time should be used for now in the TKUP RS, but it might be possible to tighten it to 1 second at a later date after vendor responses to the TKUP demonstration RFP are received.

2.2 Justification for Maintaining ≤±21 kHz Requirement for Legacy Signal Formats

During TDRS SA autotrack operations when using the current legacy signal formats, the Integrated Receiver (IR) actually performs the coherent AM demodulation process, not the current KSAR high rate equipment. The IR then sends the demodulated antenna autotrack signal to the autotrack receiver (ATR). Even if the new TKUP receiver capability is widened to ≤±54 kHz, SN support for legacy signal formats will still remain at ≤±21 kHz because upgrading the IR is outside the scope of TKUP. However, upgrading the IR or KSAF equipment can be conducted by NASA after TKUP.

Therefore, the TKUP equipment will support any future SN ≤±54 kHz legacy service upgrades, but the SN requirement in the TKUP RS must remain at ≤±21 kHz for the legacy signal formats.

An AM antenna autotrack demodulation capability for the new signal formats will be included in the TKUP equipment as stated in the TKUP RS, section 4.4, because the IR can not support AM demodulation when the new signal formats are used. The AM demodulator in the TKUP equipment will support ≤±54 kHz.

Therefore, the SN will be able to support ≤±54 kHz including antenna autotracking when using the new signal formats, but the SN will not be able to support ≤±54 kHz including antenna autotracking when using the legacy signal formats.

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CSOC-GM55-128
20 February 2001

TO: Diep Nguyen/Code 567

FROM: Mark Burns

SUBJECT: Input to KaTP SDR RFA #7, Ka-Band Dynamics Study Follow-Up, Revision 1

REFERENCES:

[1] 451-KaTP-SRD, Ka-Band Transition Product System Requirements Document, 18 December 2000.
[2] GD-WSC-2000-913-01, WSC Engineering Report, Ka-Band Dynamics Study, 15 December 2000.
[3] 405-TDRS-RP-SY-011, WSC Ground Terminal Requirements for the TDRS H,I,J Era, 8 December 1995

This memo is a revised version of the subject memo dated 26 January 2001. Revisions in this memo include the addition of Ka-band forward link dynamics impacts on WSC equipment, and information on oscillator frequency stability for Ka-band spacecraft.
Below is ITT's response to RFA#7 from the KaTP System Design Review. This RFA requested a plan to follow up on the results of the WSC Ka-band dynamics study. The text below provides a summary of the WSC study, a discussion of the current KaTP user spacecraft dynamics requirements, and recommendations to close the RFA.

A. Summary of WSC Report on KaSA Service Dynamics

WSC investigated the capabilities of the Integrated Receiver (IR), High Data Rate (HDR) Demodulator, and the Modulator/Doppler Predictor (MDP) to support KaSA service with user frequency dynamics as specified in the Ka-Band Transition Product (KaTP) System Requirements Document (SRD) [1]. The maximum user frequency dynamics requirements defined in the SRD (Section 4.2.2.3.7.1) are based on the following user range dynamics:

- Velocity: 12 km/sec
- Acceleration: 15 m/sec^2
- Jerk: 0.02 m/sec^3

It should be noted that the WSC report used ±4.5 seconds for the user ephemeris uncertainty in the frequency uncertainty calculations. Flight Dynamics has indicated to the KaTP project that a maximum ±2 second ephemeris uncertainty is feasible, and therefore the actual frequency uncertainty values will be slightly less than those indicated in the WSC report. All frequency uncertainty values used in this memo are based on a spacecraft ephemeris uncertainty of ±2 seconds

Below is a summary of the WSC study on Ka-band dynamics [2].

<u>Integrated Receiver</u>

Preliminary testing by WSC engineers has indicated that the IR may be capable of supporting the required Ka-band tuning range of ±2422.2 kHz for 225 MHz KaSAR service. This will allow signal tracking over the full range of Doppler, oscillator uncertainty, and oscillator offset frequencies. However, the IR cannot support the acquisition search range required for KaSAR service (Mode 2A: ±12.75 kHz and Mode 2B: ±45.75 kHz). Modifications to the firmware within the IR would be necessary to support these ranges.

High Data Rate Demodulator

The HDR Demodulator cannot support the required tuning range of ±2422.2 kHz for 225 MHz KaSAR service. Preliminary investigations by WSC engineers indicate that the required modifications to extend the demodulator tuning range would be feasible. Also, the HDR Demodulator cannot support the ±45.75 kHz frequency uncertainty (acquisition search range) without modification. However, preliminary testing by WSC engineers has indicated that the HDR Demodulator may be capable of supporting the ±12.75 kHz frequency uncertainty (acquisition search range).

Modulator/Doppler Predictor

The maximum tuning range required for KaSAF service exceeds the specified value of the MDP. Preliminary testing by WSC engineers has indicated that the MDP may be capable of supporting the required Ka-band tuning range of ±2252.7 kHz. This will allow KaSAF support over the full range of Doppler, oscillator uncertainty, and oscillator offset frequencies. The required forward frequency sweep range specified in the KaTP SRD (±30 kHz) is within the MDP specified capabilities and therefore has no impact on KaSAF service. A comment was made in the WSC report that the ±30 kHz sweep range may not be adequate for a Ka-band user spacecraft. Paragraphs B and C below address this comment.

B. Discussion of KaTP User Spacecraft Dynamics Requirements

The Ka-Band user frequency dynamics defined in the KaTP SRD imply support of powered flight users, which was not intended (see Al Berndt's comments on WSC dynamics study). If these requirements were relaxed to values for typical free-flight users, the WSC receivers may be able to support the required frequency tuning range without modification. Table 1 lists the maximum range dynamics between a user spacecraft and a TDRS for various orbits.

KaSA Return Service

Table 2 provides KaSA return service Doppler calculations for various user orbits and compares these calculations with the capabilities of the WSC receivers. As shown in the table, the as-built WSC receivers may be capable of supporting the maximum frequency tuning range for typical free flight users, but will not be capable of supporting the maximum frequency uncertainty. The maximum frequency uncertainty is the sum of user spacecraft oscillator uncertainty (±10 kHz or ±43 kHz) and Doppler uncertainty resulting from a two second ephemeris uncertainty. It should be noted that the WSC study used a 4.5 second ephemeris uncertainty value and therefore obtained a larger value for maximum frequency uncertainty. The primary contributor to the maximum frequency uncertainty is the spacecraft oscillator uncertainty as seen in Table 2. Hardware and/or firmware modifications to the WSC receivers would be required to support a 225 MHz KaSAR user with the oscillator uncertainty specified in the KaTP SRD regardless of the user orbit.

The spacecraft oscillator uncertainty requirements of ±10 kHz and ±43 kHz in the KaTP SRD for KaSA return service were obtained from the TDRS II Project baseline requirements document. The current TDRSS Ku-band spacecraft oscillator uncertainty requirement are ±5 kHz and ±20 kHz. The maximum spacecraft oscillator uncertainty that the WSC receivers can support at Ka-band without modification is ±6 kHz and ±21 kHz (as shown in Table 2 under "Revised KaTP SRD Rqmt" column).

KaSA Forward Service

Table 3 provides KaSA forward service Doppler calculations for various user orbits and compares these calculations with the capabilities of the WSC MDP. As shown in the table, the as-built WSC MDP may be capable of supporting the maximum frequency tuning range for typical free flight users. The sweep range of ±30 kHz in the KaTP SRD for KaSA forward service was obtained from reference [3]. This is the same value used for KuSAF service and therefore is within the capabilities of the MDP. If the spacecraft oscillator uncertainty values for KaSA return service are revised in the KaTP SRD to ±6 kHz and ±21 kHz as discussed below, the required ±30 kHz sweep range will be adequate to support a Ka-band user spacecraft.

C. Recommendations

User Spacecraft Dynamics

It is recommended that the KaTP SRD be revised to reduce the maximum user spacecraft range dynamics that the KaSA service must support.

From:

- Velocity: 12 km/sec
- Acceleration: 15 m/sec^2
- Jerk: 0.02 m/sec^3

To:

- Velocity: 7.9 km/sec
- Acceleration: 11.4 m/sec^2
- Jerk: 0.013 m/sec^3

These range dynamics would support free-flight users with circular orbit at altitudes of 125 km or greater and inclinations of 98.2 degrees or less. Currently there are no known powered-flight users that require TDRSS KaSA services.

User Spacecraft Oscillator Uncertainty

It is recommended that the KaTP SRD be revised to reduce the maximum user spacecraft oscillator uncertainty that the KaSA service must support.

From:

- Normal Oscillator Uncertainty (Mode 2A): ±10 kHz
- Extended Oscillator Uncertainty (Mode 2B): ±43 kHz

To:

- Normal Oscillator Uncertainty (Mode 2A): ±6 kHz
- Extended Oscillator Uncertainty (Mode 2B): ±21 kHz

This revision will eliminate the need to modify the WSC receivers, and therefore reduce the overall risk of the KaSA service implementation. The revision will also ensure that the current ±30kHz sweep range of the MDP is capable of supporting a Ka-band forward service. If in the future, a Ka-band user is identified that cannot meet the revised oscillator uncertainty requirements in the KaTP SRD, WSC receiver modifications could be performed at that time. However, a vendor survey has indicated that space qualified oscillators, available commercially, can support the revised oscillator uncertainty values at TDRSS Ka-band frequencies (see Appendix A).

D. Summary

<u>KaSA Return Service</u>

Preliminary testing by WSC engineers has indicated that the WSC IR and HDR demodulator capabilities may exceed their specified values for tuning range and frequency uncertainty. Additional testing should be performed on the WSC IR and HDR demodulator to better characterize their performance. If the results from additional testing are consistent with the preliminary test results, and the above revisions to the KaTP SRD are implemented, the IR and HDR demodulator will be capable of supporting TDRSS KaSAR 255 MHz service without modification.

<u>KaSA Forward Service</u>

Preliminary testing by WSC engineers has indicated that the MDP capabilities may exceed their specified values for tuning range. Additional testing should be performed on the MDP to better characterize its performance. If the results from additional testing are consistent with the preliminary test results, and the above revisions to the KaTP SRD are implemented, the MDP will be capable of supporting TDRSS KaSAF service without modification.

Table 1. Maximum Range Dynamics between a USAT and TDRS for Various Orbits

Orbit	Range Rate	Acceleration	Jerk	Source
Circular 125 km, 98.2° incl	7.9 km/s	11.4 m/s^2	.013 m/s^3	1
Circular, 200 km, 28° incl	7.4 km/s	9.8 m/s^2	.011 m/s^3	2
Circular, 200 km, 65° incl	7.6 km/s	10.4 m/s^2	.012 m/s^3	2
Circular, 200 km, 98.2° incl	7.8 km/s	11.2 m/s^2	.013 m/s^3	2
Circular, 1000 km, 65° incl	7.2 km/s	8.4 m/s^2	.0018 m/s^3	1
GEO transfer (powered flight)	11.1 km/s	14.4 m/s^2	.0221 m/s^3	3
S-805-1 Requirement	12 km/s	15 m/s^2	.20 m/s^3	
STGT Requirement, KSAR	12 km/s	15 m/s^2	.02 m/s^3	
KaTP Requirement, KaSAR	12 km/s	15 m/s^2	.02 m/s^3	

1. ITT CLASS analysis
2. Constraints on USAT Dynamics for TDRS H, I,J KaSA Service, Stanford Telecom, 2/94.
3. Range Dynamics of the TDRS-to-User Signal Path for Stable Orbits, memo from L.P. Riddle, J.R. Ransom to Code 405, 3/78.

Table 2. Doppler Calculations for TDRSS 225 MHz KaSAR Users

Parameter	Units	User Spacecraft Parameter Values					Integrated Receiver		High Data Rate Demodulator	
		KaTP SRD Rqmt	125 km, 98.2° Incl. Orbit	200 km, 28° Incl. Orbit	200 km, 98.2° Incl. Orbit	Revised KaTP SRD Rqmt	Specification	Design Impacts	Specification	Design Impacts
Maximum User Frequency	GHz	27.48	27.48	27.48	27.48	27.48				
Range Rate	km/sec	12.00	7.90	7.40	7.80	7.90				
Range Accel.	m/sec^2	15.00	11.38	9.80	11.20	11.40				
Jerk	m/sec^3	0.020	0.013	0.011	0.013	0.013				
USAT Freq Offset	kHz	1280.00	1280.00	1280.00	1280.00	1280.00				
USAT Osc. Uncert. (Mode 2A)	kHz	10.00	10.00	10.00	10.00	6.00				
USAT Osc. Uncert. (Mode 2B)	kHz	43.00	43.00	43.00	43.00	21.00				
Ephemeris Uncertainty	sec	2.00	2.00	2.00	2.00	2.00				
									Tracking	
Doppler	kHz	1099.20	723.64	677.84	714.48	723.64	1972.00	None	1300.00	None
Doppler Rate	Hz/sec	1374.00	1042.41	897.68	1025.92	1044.24	1500.00	None	1500.00	None
Doppler Accel.	Hz/sec^2	1.83	1.19	1.01	1.19	1.19	2.00	None	2.00	None
Doppler + USAT Frequency Offset	kHz	2379.20	2003.64	1957.84	1994.48	2003.64				
							Acq. & Tracking		Acquisition	
Doppler Uncertainty	kHz	2.75	2.08	1.80	2.05	2.09	3.40	None		
Doppler Rate Uncertainty	Hz/sec	3.66	2.38	2.02	2.38	2.38	4.50	None		
Dop. Uncert. + Oscil Uncert. (Mode 2A)	kHz	12.75	12.08	11.80	12.05	8.09	8.40	F/W mods	8.40	TBD (Note 3)
Dop. Uncert. + Oscil Uncert. (Mode 2B)	kHz	45.75	45.08	44.80	45.05	23.09	23.40	F/W mods	24.00	F/W Mods.
Total Required Tuning Range										
Normal Freq. Uncert. (Mode 2A)	kHz	2389.20	2013.64	1967.84	2004.48	2009.64	1972.00	TBD (Note 1)	2100.00	TBD (Note 2)
Extended Freq. Uncert. (Mode 2B)	kHz	2422.20	2046.64	2000.84	2037.48	2024.64	1972.00	TBD (Note 1)	2100.00	TBD (Note 2)

NOTES:

1. Preliminary WSC testing indicates that the IR may be capable of supporting tuning ranges up to 2422.2 kHz.
2. If the KaTP SRD requirement is relaxed to reflect typical free flight user orbits, the Ka-band tuning range is within the HDR Demodulator specification.
   If the KaTP SRD requirement is not relaxed, F/W or H/W modifications to the HDR Demodulator would be required.
3. Preliminary WSC testing indicates that the HDR Demodulator may be capable of supporting frequency uncertainties up to 24 kHz (Mode 2A).
4. Shading indicates parameter values that exceed receiver capabilities.

Table 3. Doppler Calculations for TDRSS KaSAF Users

Parameter	Units	User Spacecraft Parameter Values					Modulator/Doppler Predictor	
		KaTP SRD Rqmt	125 km, 98.2° Incl. Orbit	200 km, 28° Incl. Orbit	200 km, 98.2° Incl. Orbit	Revised KaTP SRD Rqmt	Specification	Tested Capabil.
Maximum User Frequency	GHz	23.55	23.55	23.55	23.55	23.55		
Range Rate	km/sec	12.00	7.90	7.40	7.80	7.90		
Range Accel.	m/sec^2	15.00	11.38	9.80	11.20	11.40		
Jerk	m/sec^3	0.020	0.013	0.011	0.013	0.013		
USAT Freq Offset	kHz	1280.00	1280.00	1280.00	1280.00	1280.00	700.00	
USAT Oscillator Uncertainty	kHz	27.65	28.21	28.46	28.24	28.21		
Ephemeris Uncertainty	sec	2.00	2.00	2.00	2.00	2.00		
Doppler	kHz	941.84	620.04	580.80	612.20	620.04	560.00	
Doppler Rate	Hz/sec	1177.30	893.18	769.17	879.05	894.75	700.00	
Doppler Accel.	Hz/sec^2	1.57	1.02	0.86	1.02	1.02	1.00	
Doppler + USAT Frequency Offset	kHz	2221.84	1900.04	1860.80	1892.20	1900.04		
Doppler Uncertainty	kHz	2.35	1.79	1.54	1.76	1.79		
Doppler Rate Uncertainty	Hz/sec	3.14	2.04	1.73	2.04	2.04		
Doppler Uncert. + Oscillator Uncert.	kHz	30.00	30.00	30.00	30.00	30.00	30.85	
Total Required Tuning Range	kHz	2251.84	1930.04	1890.80	1922.20	1930.04	1290.85	2600.00

NOTES:

1. Preliminary WSC testing indicates that the MDP may be capable of supporting tuning ranges up to 2600 kHz.

Appendix A
Oscillator Stability for Ka-Band User Spacecraft

This appendix summarizes the findings of a survey on spacecraft oscillator frequency uncertainty in support of the KaTP System Design Review RFA #7. Table A-1 lists the oscillator frequency uncertainty values that are currently in the KaTP SRD and recommended oscillator frequency uncertainty values as discussed in this memo. The table also lists the necessary oscillator frequency stability for the recommended oscillator uncertainty values at the maximum KaSA return frequency of 27.4784 GHz.

Table A-1 Required and Recommended Spacecraft Oscillator Uncertainty

Required Spacecraft Oscillator Uncertainty in KaTP SRD	Recommended Spacecraft Oscillator Uncertainty	Necessary Oscillator Frequency Stability (at 27.4784 GHz) for Recommended Uncertainty
Mode 2A: ±10 kHz	Mode 2A: ±6 kHz	$2.18x10^{-7}$
Mode 2B: ±43 kHz	Mode 2B: ±21 kHz	$7.64x10^{-7}$

Table A-2 summarizes key results from the vendor survey of frequency oscillators that could potentially support NASA Ka-band missions. The vendor survey was performed to determine if oscillators were commercially available that could support the recommended oscillator frequency uncertainty numbers and frequency stability numbers listed in column 2 and column 3, respectively, of Table A-1. As seen in Table A-2, two of the vendors surveyed provide spacecraft oscillators that will meet the worst case (Mode 2A) frequency stability requirement of $2.18x10^{-7}$.

Table A-2 Summary of Frequency Stability for Commercially Available Oscillators

	Vendor			
Oscillator Characteristics	Wenzel Associates		Syntonics	
Output Frequency	10 MHz	10 MHz	115 MHz	19.12 MHz
Frequency Stability over Temperature	$1x10^{-7}$ (-20 to +70C)	$1x10^{-8}$ (-20 to +70C)	$1.7x10^{-12}$ (+20 to +40C)	$1x10^{-12}$ (+20 to +40C)
Frequency Stability over Time	Not specified	$1x10^{-10}$ (per day)	$1.7x10^{-11}$ (per day)	$2x10^{-11}$ (per day)
Space Qualified	Yes	No	Yes	Yes
Applications	Mars Pathfinder and Near Earth Asteroid Rendezvous spacecraft		Cassini, Mars Observer, and TOPEX spacecraft	

REQUEST FOR ACTION (RFA)

1. *Review Type*	2. *RFA No.*	3. *Review Date*
TKUP System Requirements Review	452/230-007	April 27, 2005

4. *Title*

Bit Transition Density

5. *Action*

Check normal transition density ≥40% for mean-time between slip ≥90 minutes. 40% may be the requirement but it seems unrealistic.

Reference

Page 75

6. *Originator/Organization/Telephone No./E-mail*

Ken Perko/GSFC/Code 567/ for Victor Sank/MEI/Code 567/301.286.2645/ Victor.Sank@gsfc.nasa.gov

7. *Assigned To/Organization/Telephone No./E-mail*	*Due Date*
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/13/05

8. *Response*

The TKUP Requirements Specification (RS) should not be changed. Based on the main objective of TKUP, which is to address equipment obsolescence, the TKUP RS needs to preserve each legacy requirement unless NASA changes the scope of the TKUP.

Please see attachment for additional details and legacy requirement traceability.

9. *Response By/Organization/Telephone No./E-mail*	*Date Prepared*
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/13/05

10. *Originator Contacted*	☐ *No*	☒ *Yes*	*Date*	5/16/05

11. *Disposition*	☐ *Open*	☐ *Deferred*	☒ *Closed*	☐ *Withdrawn*

12. *Comments*

Re-evaluating current SN legacy requirements is outside the scope of TKUP. Therefore in being compliant with the high level requirement to support SN legacy requirements the 452-RS-TKUP requirement for bit transition density will remain as it is currently specified (which is consistent with current SN legacy requirements). The originator still desired a change in the requirement but agreed this change is outside the scope of the TKUP to resolve. No further TKUP action is needed.

13. *Approval*

Signature on file; see email dated Fri, 8 Jul 2005 08:52:41 -0600
John B. Martin

Date

1.0 Legacy Requirement Traceability

Currently, the mean time between bit slips in 530-RSD-WSC, paragraph 5.3.2.3.2.8, and the SNUG (450-SNUG, revision 8, Paragraph 7.3.3.3.b) is stated in the TKUP Requirements Specification (RS), paragraph 4.3.5.4, as follows:

Normal Transition Density:

For the bit transition density and C/N_o defined below, the receiver equipment shall be capable of providing a mean time between bit slips of ≥90 minutes for the I and Q channels when bit slip is caused by a cycle slip in the bit recovery loop:

- Bit Transition Density. NRZ symbols: ≥40%
- C/N_o. The C/N_o is at a level that is greater than or equal to a level that produces a BER of 10^{-5} at the output of the receiver equipment.

Low Transition Density:

For the bit transition density and C/N_o defined below, the receiver equipment shall be capable of providing a mean time between bit slips of ≥90 minutes for the I and Q channels when bit slip is caused by a cycle slip in the bit recovery loop:

- Bit Transition Density. NRZ symbols: ≥25% and ≤40%
- C/N_o. The C/N_o is at a level that is greater than or equal to a level that is 1 dB greater than the level required for a BER of 10^{-5} at the output of the high rate receiver equipment.

The 40% and 25% bit transition requirements are referenced to a 100% bit transition that is defined as follows: 1010101010

If the 40% requirement is unrealistic in the operational environment, the 25%-40% requirement can be used by the customer.

2.0 Scope Of TKUP

Based on the main objective of TKUP, which is to address equipment obsolescence, the TKUP RS needs to preserve each legacy requirement unless NASA changes the scope of the TKUP.

REQUEST FOR ACTION (RFA)		
1. *Review Type* TKUP System Requirements Review	2. *RFA No.* 452/230-008	3. *Review Date* April 27, 2005

4. *Title*
Considerations for modulation vs. data rate cut-offs

5. *Action*
Allow for some overlap in modulation type vs. data rate to allow use of commercial standards. For example, Intelsat cut-off for QSPK to 8 PSK is lower than 410 Mbps. Use of 8 PSK at lower rates will also be necessary for future spectrum management issues.

Reference
Page 12

6. *Originator/Organization/Telephone No./E-mail*
Dave Israel/GSFC/Code 567/301.286.5294/David.J.Israel@nasa.gov

7. *Assigned To/Organization/Telephone No./E-mail*	*Due Date*
Caren Gioannini / NASA WSC / Code 565 / 505.527.7026 / caren.c.gioannini@nasa.gov	5/20/05

8. *Response*
The RFA "Action" will be incorporated into the TKUP Requirements Specification (RS) by changing the low end of the 8PSK data rate requirement from 410 Mbps to 150 Mbps.

9. *Response By/Organization/Telephone No./E-mail*	*Date Prepared*
Dave Miller/ITT/703.438.7963/ David.Miller@itt.com	5/17/05

10. *Originator Contacted*	☐ *No*	☒ *Yes*	*Date*	6/01/05

11. *Disposition*	☐ *Open*	☐ *Deferred*	☒ *Closed*	☐ *Withdrawn*

12. *Comments*
Originator concurrence received via email on June 01, 2005.

13. *Approval*

Signature on file; see email dated Fri, 8 Jul 2005 08:52:41 -0600
John B. Martin

Date

REQUEST FOR ACTION (RFA)

1. Review Type	2. RFA No.	3. Review Date
TKUP System Requirements Review	452/230-009	April 27, 2005

4. Title

Tuning over 225 MHz channel

5. Action

Consider having receiver (or some other system component) capable of tuning over 225 MHz channel. The capability of supporting multiple users within one channel may be highly desirable to future exploration scenarios.

Reference

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6. Originator/Organization/Telephone No./E-mail

Dave Israel/GSFC/Code 567/301.286.5294/David.J.Israel@nasa.gov

7. Assigned To/Organization/Telephone No./E-mail	Due Date
Frank Hartman / NENS General Dynamics / 505.527.7363 / fhartman@mail.wsc.nasa.gov	5/13/05

8. Response

This suggestion has much merit, but it represents an enhancement to the KSA return service that is not driven by any specifically defined operational requirement associated with the service catalog enhancement of TKUP, and is therefore beyond the scope of TKUP. While the functional change would not represent a significant burden to the project, the change would represent a significant burden with respect to developing and verifying the performance requirements associated with services not centered in the TDRS channel; this would be required not only for the TKUP-specific configurations, but for all KSAR configurations.

If the SN were to make a commitment to enhance the KSAR 225-MHz service in this manner, it could be accomplished in the future by modifying or replacing the KSAR downconverters.

9. Response By/Organization/Telephone No./E-mail	Date Prepared
Frank Hartman / NENS General Dynamics / 505.527.7363 / fhartman@mail.wsc.nasa.gov	5/05/05

10. Originator Contacted	☐ No	☒ Yes	Date	5/11/05

11. Disposition	☐ Open	☐ Deferred	☒ Closed	☐ Withdrawn

12. Comments

Originator concurrence received verbally on May 24, 2005 and in writing on July 8, 2005.

13. Approval

Signature on file; see email dated Wed, 14 Sep 2005 19:03:08 -0400
John B. Martin

Date

REQUEST FOR ACTION (RFA)

1. Review Type	2. RFA No.	3. Review Date
TKUP System Requirements Review	452/230-010	April 27, 2005

4. Title

Criteria for coding scheme selection decision

5. Action

Develop a full set of criteria for decision-making prior to the issuance of the demonstration RFP.

Reference

6. Originator/Organization/Telephone No./E-mail

Keiji Tasaki/GSFC/Code 452/301.286.6724/Keiji.K.Tasaki@nasa.gov

7. Assigned To/Organization/Telephone No./E-mail	Due Date
Caren Gioannini / NASA WSC / Code 565 / 505.527.7026 / caren.c.gioannini@nasa.gov	5/13/05

8. Response

The criteria for selecting the coding scheme(s) to be used for TKUP will be developed in parallel with the development of the Demonstration Request for Proposal (RFP). There are factors to be considered in making this coding scheme(s) selection that do not directly result from the Demonstration activities. As a result the criteria may continue to be reviewed and solidified after the Demonstration RFP is released. In addition, assessment of the coding schemes against the criteria may begin prior to the Demonstration.

9. Response By/Organization/Telephone No./E-mail	Date Prepared
Caren Gioannini / NASA WSC / Code 565 / 505.527.7026 / caren.c.gioannini@nasa.gov	5/13/05

10. Originator Contacted	☐ No	☒ Yes	Date	5/13/05

11. Disposition	☐ Open	☐ Deferred	☒ Closed	☐ Withdrawn

12. Comments

Originator concurrence received via email on May 24, 2005.

13. Approval

Signature on file; see email dated Fri, 8 Jul 2005 08:52:41 -0600

John B. Martin

Date

450-FORM-0002 (05/04)
Revision 2